A Holocene History of the Vegetation of the Blue Mountains, New South Wales

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The Greater Blue Mountains Area has been inscribed on the World Heritage list for its exceptionally diverse *Eucalyptus* communities. Hanging swamps in this region, listed as 'vulnerable ecological communities', accumulate sediments that contain the palaeoenvironmental record. Seven of these swamps have been studied, revealing a history of the vegetation, climate and fire regimes.

Palynological analysis of each swamp reveals a history of the surrounding vegetation. There are similarities and parallel changes between some of the swamps allowing generalities about the climate of the Holocene to be made. In the early Holocene, about eleven to nine thousand years ago (11-9 ka), the vegetation was more wooded and the climate was probably somewhat warmer and wetter. By the mid Holocene about 6-4 ka, trees were less dominant in the vegetation suggesting that the climate was probably drier. By 3-2 ka, wooded vegetation had mostly returned, and after 2 ka, *Baeckea, Leptospermum, Kunzea* and *Melaleuca* species increased somewhat, with further increases in European settlement time, possibly reflecting a reduction or thinning of the wooded canopy.

Charcoal analysis of the accumulated sediments suggest that there was more fire in the early Holocene when trees increased the biomass. There was less fire through the mid Holocene when the biomass was lower, but it increased with the return to more wooded vegetation in the late Holocene. In particular, the woody shrubs of *Baeckea, Leptospermum, Kunzea* and *Melaleuca* increased with an increase in charcoal, probably because these shrubs benefit from a more open canopy, but they also grew on the swamps hence could deposit charcoal directly into the sediments. Charcoal values are particularly high after European settlement. It is possible that the disruption of Aboriginal burning practices allowed the increased growth of woody shrubs and hence a much greater fuel load.

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KEY WORDS: Blue Mountains, Climate change, Fire history, Palynology, Vegetation history.

INTRODUCTION

The Greater Blue Mountains Area was inscribed on the World Heritage List in December 2000. The Blue Mountains are a deeply incised sandstone plateau rising to over 1,300 m at its highest point. This plateau is thought to have enabled the survival of a rich diversity of plant and animal life by providing a refuge from climatic changes during the recent geological history. It is particularly noted for its wide representation of habitats, from wet and dry sclerophyll, mallee heathlands, as well as localised swamps, wetlands and grassland. Ninety one species of eucalypts are found in the Greater Blue Mountains Area and twelve of these are believed to occur only in the Sydney sandstone region (Australian Government, Department of the Environment and Water Resources, 2007a).

The area has been described as a natural laboratory for studying the evolution of the eucalypts (Australian Government, Department of the Environment and Water Resources, 2007a). The steep terrain and sharp environmental gradients have allowed for major evolutionary change in some taxa, resulting in exceptional biodiversity, particularly within the eucalypt communities that dominate the place. Importantly, the evolutionary processes underpinning this diversity are believed to be ongoing, resulting in an evolutionary 'laboratory' that is exceptional in the world (Australian Government, Department of the Environment and Water Resources, 2007a).

Peat formation on sandstone, the substrate of most of the Blue Mountains, is very unusual. The hanging swamps of the Blue Mountains are especially notable and have lower sediment loads and accumulate organic matter more slowly than valley swamps and swamps along watercourses. They are also easily eroded with any disturbance. The small geographic distribution and demonstrable threat has meant that these hanging swamps are now listed as 'vulnerable ecological communities' under the NSW Threatened Species Conservation Act of 1995 ((Australian Government, Department of the Environment and Water Resources, 2007b; Sullivan, 2007)

Seven swamps in an altitudinal sequence in

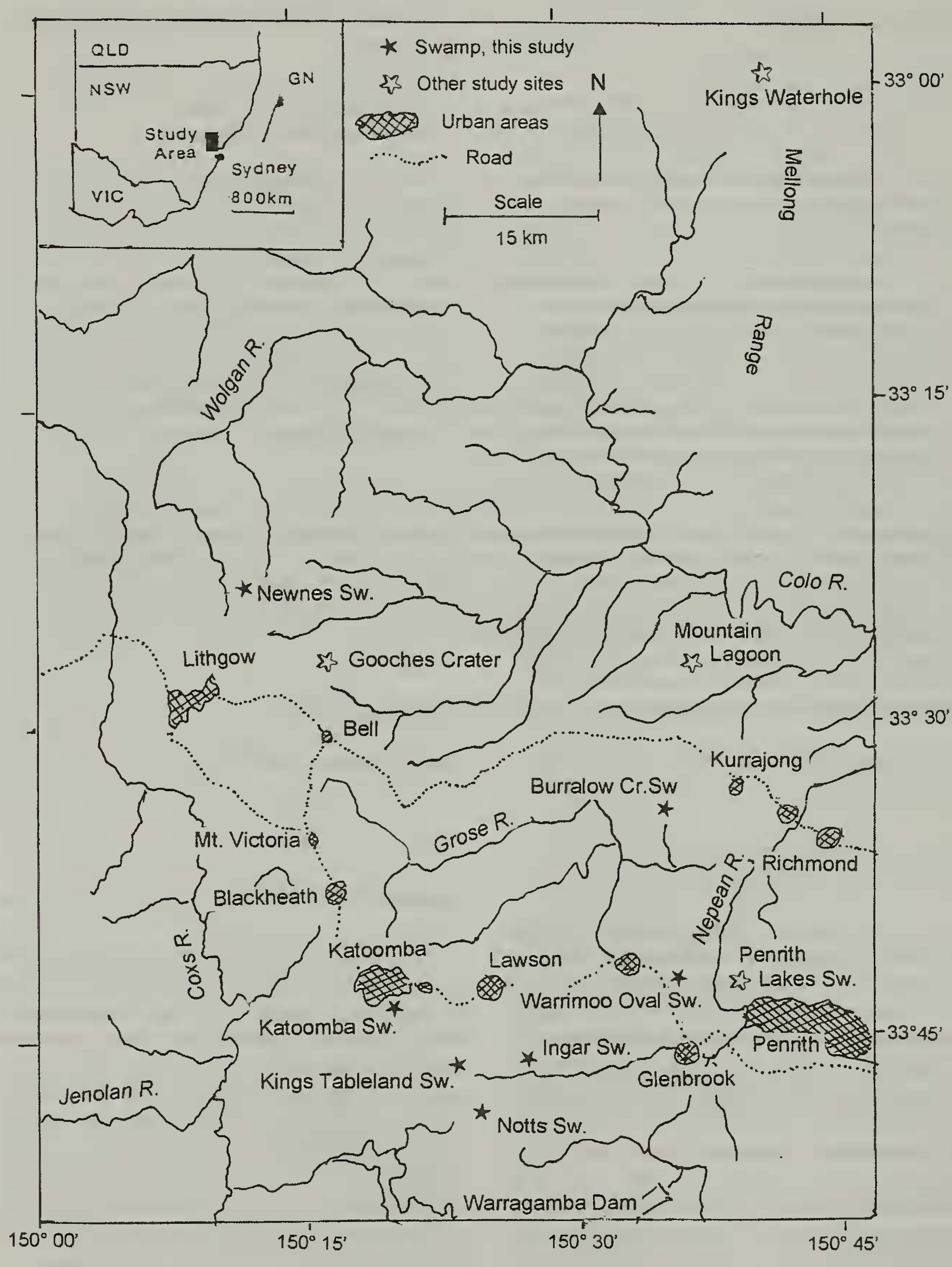


Figure 1. Locality map.

the Blue Mountains (Fig. 1) were chosen for a palynological study and are described in Chalson and Martin (this volume). A method to identify *Eucalyptus* pollen to species was developed (Chalson and Martin, 1995) with the aim of revealing the history of the eucalypt communities of the region. At the beginning of the Holocene, 10,000 years ago, the climate was approaching that of today, but there have been changes through the Holocene (Allan and Lindsay, 1998). The history of the Holocene is thus the history of vegetation very like that of today.

THE ENVIRONMENT

Geology and geomorphology

The Blue Mountains consist of a deeply dissected plateau rising from the Cumberland Plain in the east, along the Lapstone Monocline. Elevation is about 30 m in the east to over 1,000 m in the west. The sedimentary rock units are Triassic in age and curve upwards, from east to west, towards the edge of the Sydney Basin. In the east, Wianamatta Shale outcrops along the side of the Lapstone Monocline. West of the Monocline, the underlying Hawkesbury Sandstone Formation outcrops and further west, underlying the Hawkesbury Sandstone, the Grose Sub-Group of the Narrabeen Group outcrops. The Grose Sub-Group is divided into a number of formations and the ones encountered in this study are as follows: The Banks Wall Sandstone Formation, within which is found the Wentworth Falls Claystone Member, and the basal Burra-Moko Head Sandstone Formation, which is the most prominent cliff-forming unit in the Blue Mountains (Bembrick, 1980).

The plateau surface is undulating with small creeks forming upland valleys. In areas where Hawkesbury Sandstone is the underlying rock type, the upland valleys progressively increase in gradient as they incise below the plateau surface and develop steeply inclined V-shaped gorges with only minor benching in the valley sides. To the west, where the Banks Wall Sandstone formation is the underlying rock type, the valley sides and floors slope gently and the streams do not incise but flow across a series of swamps and sandy peat deposits. Eventually, the streams cut through a sandstone layer into claystone or shale when a nickpoint (often a waterfall) is formed (Langford-Smith, 1976).

The development of the swamps in these two areas varies enormously. The eastern region supports few swamps which are usually associated with large streams that have a central channel and flowing water. In the western region, there are more swamps and they are developed in broad shallow valleys with no marked central stream but rather experience a general slow flow of water across the whole area (Langford-Smith, 1976).

The climate

Maximum temperatures in the Blue Mountains relate strongly to altitude. Average January maxima are highest at the lower altitudes, 29 °C at Richmond and lowest at the higher altitudes, 23 °C at Mt. Victoria. Average minimum temperatures generally decrease from east to west. The July minima range from 3.4 °C at Richmond to –0.8 °C at Lithgow (Table 1). Temperatures as low as –3 °C have been recorded from Katoomba (BoM, 2006; Bureau of Meteorology, 1979).

Rainfall patterns relate to elevation and distance from the coast. The average annual rainfall increases from 806 mm at Richmond to 1424 mm at Newnes (Table 1). The driest months are usually July to September and the wettest are December to March (BoM, 2006; Bureau of Meteorology, 1979).

Winds from the west or northwest dominate all the year, although there are significant easterly and northeasterly winds during the summer months of November to April. Fogs frequently occur on the higher Blue Mountains, with Katoomba and Mt. Victoria recording an average of 55 and 90 fog days per year, respectively (BoM, 2006). Frosts occur on 35 to 40 days of the year, mostly between April and November. Snow falls most frequently in July and August: Katoomba and Mt. Victoria have and average of 3 and 10 snow days per year, respectively (Bureau of Meteorology, 1979).

Soils

The quartz-rich sandstones in the area are low in most nutrients, and thus soil and alluvium derived from sandstones are low in nutrients. The soils are mainly lithosols and yellow podzolics with small areas of red and lateritic podzolic soils and sandy alluvial soils in the valleys. Most of the soils are moderately acidic, with pH values of 4.5 to 5. In rugged terrain, rock commonly lies near or at the surface. The soil fertility in the valleys may be higher because of the accumulation of organic matter (Chalson, 1991)

Vegetation

The vegetation is almost entirely dry sclerophyll woodland and open forest, the 'Sydney Sandstone Complex' (Keith and Benson,1988) with localised swamps in the valleys. There are small patches of tall open forest or wet sclerophyll in specially favourable habitats, such as protected gorges. Heathlands are found in the harshest environments.

Table 1. Climatic Averages. Stations are arranged according to altitude.

Station and altitude (m)	Mean max. temp, hottest month, (Jan.) °C	Mean min. temp, coldest month, (June or July) °C	Mean annual rainfall, mm
[1]Richmond, 19-20 [3]	29.5	3.4	806
[2]Penrith, 27	-	-	786
[2]Springwood ~400	-	-	1076
[2]Kurrajong Heights, ~550	-	-	1253
[2]Lawson, 715	-	-	1260
[2]Wentworth Falls, ~900			1409
[1]Lithgow (Birdwood St.), 950	25.5	0.7	860
[1]Katoomba, 1030	23.1	2.5	1398
[1] Mt Victoria, 1064	23.0	1.7	1061
[2]Blackheath PO, 1065	-	-	1145
[1]Lithgow (Newnes Forest Centre), 1050	23.2	-0.8	1072

1 From BoM (2007). 2 From Bureau of Meteorology (1979)
3 Average of Richmond RAAF and Richmond UWS Hawkesbury

Open forest with *Angophora costata*, *Eucalyptus piperita*, *E. agglomerata* and *Syncarpia glomulifera* dominant is found in sheltered gullies with moist, well-drained soils on the Hawkesbury and Narrabeen Group sandstones. The understorey includes small trees of *Allocasuarina torulosa* and *Acacia elata*, with shubs of *Hakea dactyloides*, *Pultenaea flexilis* and *Dodonaea triquetra*. Tall open forest is restricted to the more sheltered gorges and is dominated by *E. deanei* with *Syncarpia glomulifera*, *Acacia elata*, *Ceratopetalum apetalum*, *Callicoma serratifolia* and *Angophora floribunda*. There is a distinctive riparian scrub of *Tristaniopsis laurina* and *Backhousia myrtifolia* along the larger water courses (Keith and Benson,1988),

Woodland and low woodland with *Corymbia gummifera*, *Eucalyptus sclerophylla* and *E. oblongata* dominant is widespread on ridges and open slopes on shallow, well-drained soils of the Hawkesbury and Narrabeen Group sandstones. *E. punctata*, *E. piperita* and *Angophora costata* may be present in the more sheltered sites. *E. sclerophylla* is particularly common on damper soils. The understorey is rich in shrubs of the Proteaceae, Myrtaceae and Fabaceae (Keith and Benson,1988).

There are other woodlands: the 'Tablelands Grassy Woodland Complex' with *Eucalyptus dives*, *E. mannifera*, *E. eugenioides*, *E. pauciflora*, *E. rubida*, *E. aggregata* and *E. stellulata* the common species. The 'Snow Gum Woodland' has *E. pauciflora*, *E. dalrympleana*, *E. rubida* and *E. stellulata* dominant (Keith and Benson,1988).

Open heath communities have *Eucalyptus stricta*, *Allocasuarina nana* and *Leptospermum trinervium, Phyllota squarrosa*, *Eriostemon obovalis*, *Epacris reclinata*, *Dracophyllum secundatum* and *Gleichenia rupestris* dominant. *Phyllota squarrosa* and *Eriostemon obovalis* are common in montane heaths whereas *Phyllota phylicoides* and *Eriostemon hispidula* are common on the Lower Blue Mountains heath. Many other smaller shrubs are found in these heath communities (Keith and Benson,1988).

Closed heath or 'Newnes Shrub Swamps' have *Leptospermum lanigerum*, *Baeckea linifolia*, *Grevillea acanthifolia* and *Xyris ustulata* dominant. They are found in shallow valleys above 1,000 m elevation in swamps, with poorly drained, acid and sandy peat soils. There is a ground cover of sedges including *Baloskion australe*, *Empodisma minus*, *Lepyrodia scariosa*, *L. anathria*, *Lepidosperma limicola* and small shrubs (Keith and Benson,1988).

Closed sedgeland, the 'Blue Mountains Sedge Swamps', have *Gymnoschoenus sphaerocephalus*, *Lepidosperma limicola*, *Xyris ustulata* and *Baeckea linifolia* dominant. These sedge swamps are found at lower altitudes than the closed heath swamps and occupy steep-sided basins (the 'hanging swamps'). They are intermittently waterlogged and have shallow sandy soils. Many sclerophyllous shrubs form an open heath (Keith and Benson,1988).

For a full description of the specific vegetation found at each site, see Chalson and Martin (this volume).

Human Occupation

The Blue Mountains, especially the lower part, was highly favourable to the hunter-gatherer, (Stockton,1993a). Movement was relatively easy on the ridges, water was not scarce while flora and fauna suitable for food were both plentiful and varied. The rivers were also a source of rock types used for tool making.

Campsites with an abundance of worked stone were particularly common in the Lower Blue Mountains. In the Upper Mountains, there were fewer campsites than in the Lower Mountains, but their concentration of flaked stone showed that they have been equally well used. The Central Mountains reveal many rockshelter sites where there were fewer stone artifacts than the Upper and Lower Mountains. However, there was a high concentration of rock art, engravings, paintings and axe grinding grooves. This suggests that the Upper and Lower Mountains were used for survival but the Central Mountains were more of religious and ritual significance (Stockton,1993a).

It is generally presumed that the climate in the Blue Mountains was too severe for year-round occupation during the ice age. However, protected sites such as the rock shelters would have been livable, especially if protected from the bitter westerly winds. (Stockton,1993b).

The oldest signs of occupation in the Blue Mountains were found at Kings Tableland, Wentworth Falls with the oldest date of 22,240 years BP. Walls Cave at Blackheath and Lyre Bird Dell, Leura both yielded dates of more than 12,000 years BP. There were other sites, e.g. Hazelbrook, to 7,200 years BP, Springwood Creek Rock Shelter, from 8,500 years BP up to European times and open sites, e.g. Jamison Creek. Evidence from the Nepean River, at the foot of the Blue Mountains suggests human occupation could go back to 40,000 years BP. In all, there were over 700 Aboriginal sites in the Blue Mountains (Stockton, 1993b; Attenbrow, 2002).

With the coming of Europeans, both Europeans and Aborigines avoided each other and early travelers in the Mountains rarely saw any Aborigines. Settlers followed the first crossing of the Mountains in 1813 by Blaxland, Lawson and Wentworth (Breckell, 1993) After some skirmishes about the land the settlers had taken, Aborigines and Europeans co-existed, though not without racist incidents (Smith, 1993).

METHODS

Seven swamps in an altitudinal sequence were chosen for study and they are described in Chalson and Martin (this volume). A study of the pollen in surface samples from swamps (Chalson and Martin this volume) provides insights that assist in the interpretation of the pollen spectra from the sediments. The description of the vegetation at each site is also presented in Chalson and Martin (this volume).

The swamps were systematically probed to identify the area where accumulating sediments were the deepest, using a Russian D-corer (Birks and Birks, 1980). The sediments and stratigraphy were described using the terminology of Birks and Birks (1980) Samples for radiocarbon dating were taken from a pit where possible, otherwise with repeated use of the D-corer until sufficient sediment was acquired. The standard radiocarbon dates were calibrated using the CalPal (Version March 2007) program.

Samples of sediment were taken from the core every 10 cm, or where it was thought there could be a critical change, every 5 cm. For pollen preparations, the core sediments were spiked with *Alnus* of a known concentration, treated with hydrochloric and hydrofluoric acids to remove siliceous material (Birks and Birks, 1980), oxidised with Schultz solution (a saturated solution of potassium perchlorate in nitric acid), cleared in 10% potassium carbonate and the residue was mounted in glycerine jelly (Brown, 1960). Reference pollen was treated with standard acetolysis (Moore et al., 1991) and also mounted in glycerine jelly.

Pollen was identified by comparing grains from the core with a collection of reference pollen. Special attention was paid to pollen of the family Myrtaceae which may be identified to species following the method in Chalson and Martin (1995).

Pollen was counted along transects across the slides and tests showed that a count of more than 140 grains adequately sampled the residues. The counts were presented as percentages of the total count and pollen concentrations were calculated for the most abundant pollen groups. Percentages are relative and a change in a single pollen group will affect percentages of all the other groups, but presenting both percentages and concentrations will reveal fluctuations in individual pollen groups.

The abundance of charcoal retained on a 150 μm sieve, as part of the palynological preparation, was estimated subjectively on a scale of 0 to 8. Counts of microscopic charcoal for a swamp at Kings Tableland showed that the two methods gave similar results, although the microscopic charcoal was more variable (Chalson, 1991).

RESULTS

Burralow Creek Swamp

Burralow Creek Swamp, at 33° 32'S, 150° 36' 38"E and 310-330 m altitude, is situated in a narrow V-shaped valley and follows the course of the creek for some 3.5 km. The substrate is Hawkesbury Sandstone, but Wiananatta Shale outcrops on the surrounding ridge-tops. The upper reaches of Burralow Creek drain urban areas and farmland areas. An isolated farm adjacent to the swamp was incorporated into the Blue Mountains National Park. Weed growth from this farm is confined to a small area and has not spread into the adjacent bushland.

Stratigraphy: Sediments were recovered to a depth of 310 cm. Clayey peat was found down to 10 cm, humic clay at 15-50 cm and humic sandy clay at 60-70 cm. Sand was encountered at 80-260 cm and clay/sand at 260-310 cm. The radiocarbon dates are presented in Table 2.

Swamp vegetation and surface pollen: Species of *Kunzea* and *Leptospermum* were dominant on the swamp but Restionaceae, Cyperaceae and *Selaginella* species were also present (Chalson and Martin, this volume). Surface sample pollen from the swamp (Chalson and Martin, this volume) showed appreciable *Leptospermum/Baeckea* and a considerable amount of Restionaceae or Cyperaceae in some samples. The fern spore content was low.

The pollen record: The pollen spectra from the sediments is presented in Figs 2A, 2B and has been divided into the following zones:

310 to140 cm, no pollen recovered.

Zone E, 130 cm, age ? > 1,200 cal yr BP (see Fig. 3 for estimated ages). *Angophora floribunda*, *Eucalyptus* spp. and possibly Casuarinaceae pollen were the most abundant of the possible arboreal groups. There was a moderate representation of Poaceae and *Selaginella* (Fig 2A) and other shrubs and herbs were present in low frequencies (Fig 2B).

120-110 cm, no pollen recovered.

Zone D, 100-90 cm, age c. 1,200 –1,000 cal yr BP . This zone had a very high proportion of *Selaginella* spores and low proportions of everything else, including tree pollen. The pollen concentrations showed a similar pattern to that of the percentages which revealed a change in the whole pollen spectrum, not only reflecting the addition of a large number of *Sellaginella* spores to spectra otherwise like that in zone E.

Zone C, 80-60 cm, age c. 1,000-800 cal yr BP The Sellaginella content had decreased considerably when compared with the zone brlow, There was a high proportion of Casuarinaceae and Myrtaceae, including *Eucalyptus* species and the Poaceae content was low.

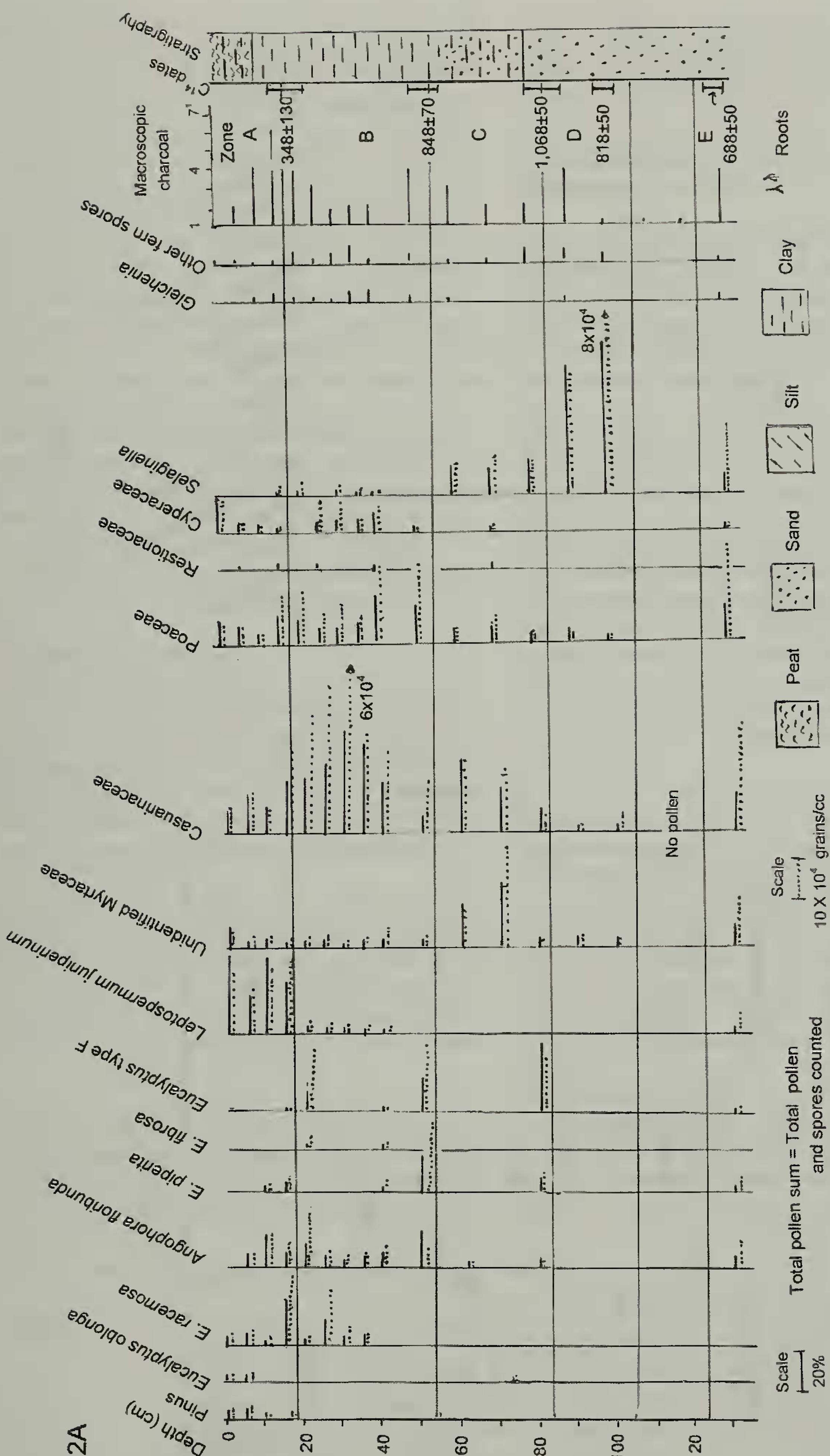
Zone B, 50-20 cm, age c.8700-250 cal yr BP. The Casuarinaceae content had increased and was the highest for the profile. *Eucalyptus* species and *Angophora floribunda* were well represented and *Leptospemum juniperinum* was present in low frequencies. There was a moderate content of Poaceae and Cyperaceae, with a diversity of fern spores. *Sellaginella* content was minimal.

Zone A, 15-0 cm, age c. 250-present, cal yr BP. European *Pinus* was found in this Zone and there was a high content of *L. juniperinum*. There was some change in the *Eucalyptus* species, Casuarinaceae declined. and the Poaceae content was moderate, when compared with the zone below.

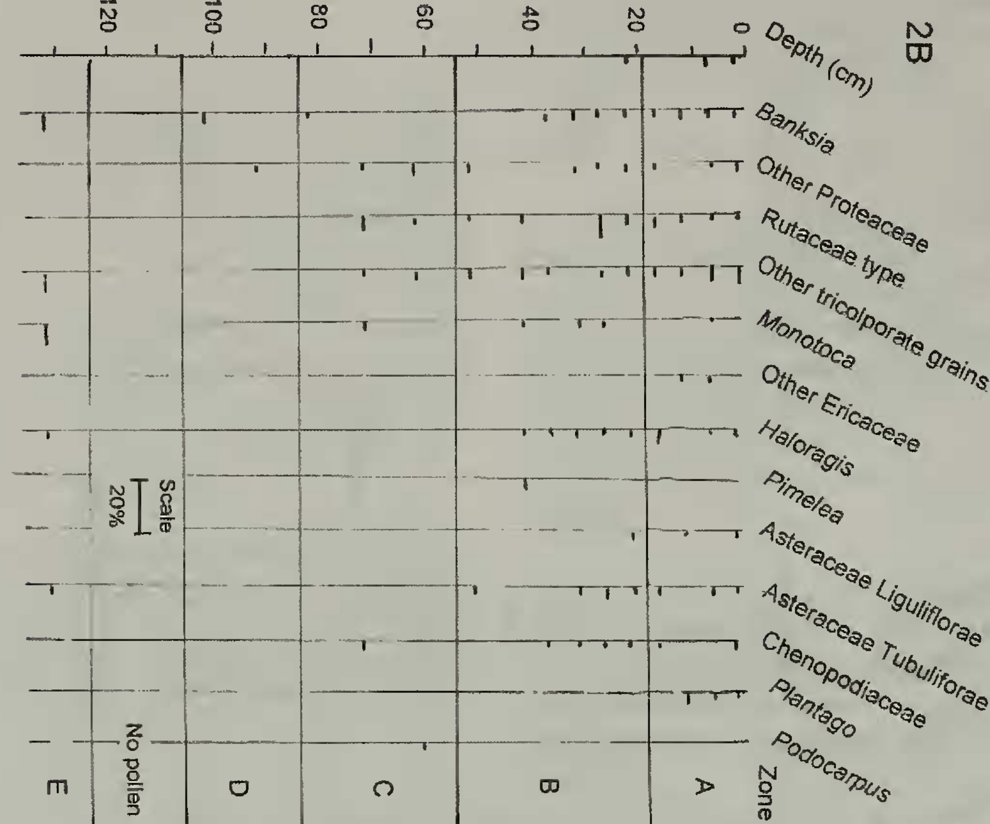
Charcoal content was low to moderate through most of the profile, with a somewhat higher content at the base of Zone A, the zone of European influence.

Table 2. Radiocarbon ages for Burralow Creek Swamp

Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP)	Calibrated age (cal yr BP.)
15-20	Humic clay	SUA-2607	250 ±50	348±130
50-60	Humic sandy clay	SUA-2608	830±60	848±70
80-90	Sand	SUA-2609	1,070±50	1068±50
95-105	Sand	SUA-2610	820±50	818±50
125-135	Sand	SUA-2611	660±55	688±50



Figures 2A, 2B. Burralow Creek Swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.



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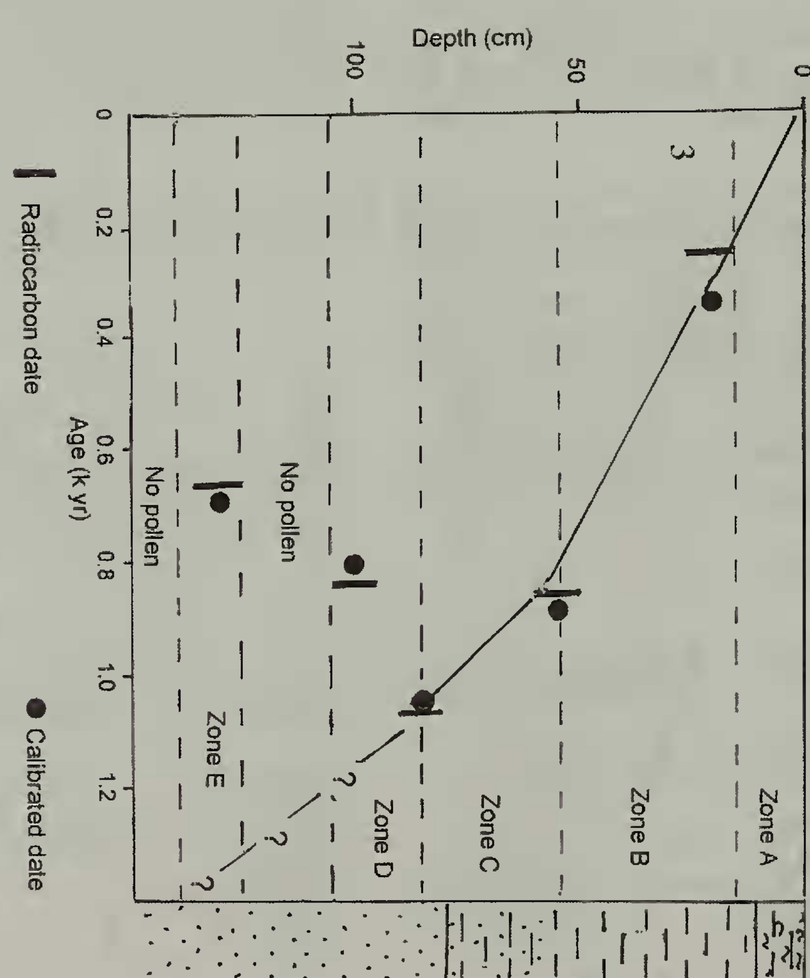


Figure 3. Burralow Creek Swamp summary diagram.

History of the vegetation: Initially, more than 1,200 cal yr BP, there was a mixed tree cover of Myrtaceous species and possibly Casuarinaceae with a moderate Poaceae understorey. *Selaginella*, was prominent on the swamp. A period of possibly a reduced tree cover followed, with an expanded swamp area with abundant *Selaginella* about 1.2-1.0 cal ka. Alternatively, if the swamp area was larger, the trees may have been further away, hence they contributed less pollen to the spectrum. The tree cover increased and *Selaginella* was much reduced by about 1-0.8 cal ka. At this time, the clay content of the sediments increased, perhaps indicating a less energetic water flow. Casuarinaceae became prominent about 0.8-0.25 cal ka with less Myrtaceae, although a diversity of species was identified. Simultaneously, *Sellaginella* decreased while Cyperaceae and Poaceae increased. In the European zone, there was some change in *Eucalyptus* species and a big decline in Casuarinaceae while *Leptospermum juniperinum* became prominent.

Fire was a constant factor in the environment, especially in the early part of the European zone.

Warrimoo Oval Swamp

Warrimoo Oval Swamp, at 33° 43' 21.44"S, 150° 36' 58.35"E and 190-200 m altitude, is situated in a V-shaped valley with a stream flowing through it. The substrate is Hawkesbury Sandstone, but Wiananatta shale outcrops on the surrounding ridge-tops. Substantial urban areas occur within a kilometre from the swamp and weed invasion is considerable.

Stratigraphy: Total depth recovered was 250 cm. The top 20 cm was peat, then sandy peat down to 50 cm. A layer of sand was found between 50 and 90 cm, then sandy silt down to 200 cm, then sand down to 250 cm when coring stopped (Fig. 4A). The radiocarbon dates are given in Table 3.

Swamp vegetation and surface pollen: Species of *Baeckea, Kunzea* and *Leptospermum* were dominant on the swamp. Cyperaceae, Juncaceae and *Gleichenia* species were also present (Chalson and Martin, this volume). The pollen spectra from the surface samples (Chalson and Martin, this volume) contained appreciable *Melaleuca*, *Baeckea/Leptospermum* and *Gleichenia* species.

The pollen record: The pollen spectra from the sediments are shown in Figs 4A, 4B.

Zone B, 250-130 cm, c. 4,700-2,200 cal yr BP (for estimated ages, see Fig. 5). Abundant *Gleichenia* denoted this zone, The Myrtaceae content was low, with some of the pollen identifiable to genus/species. There was a consistent content of Casuarinaceae and *Haloragis,* and Poaceae was almost entirely absent.

Zone A, 120 cm to surface, c. 2,200-present cal yr BP. There was very little *Gleichenia*,, together with an increase in the Myrtaceae and Casuarinaceae content, when compared with the zone below. The Poaceae, Cyperaceae and Restionaceae content was higher and the pollen flora considerably more diverse when compared the preceding zone. *Pinus* was found down to a depth of 20 cm, thus denoting the European influence, where *Baeckea/Leptospermum* species increased and Casuarinaceae decreased.

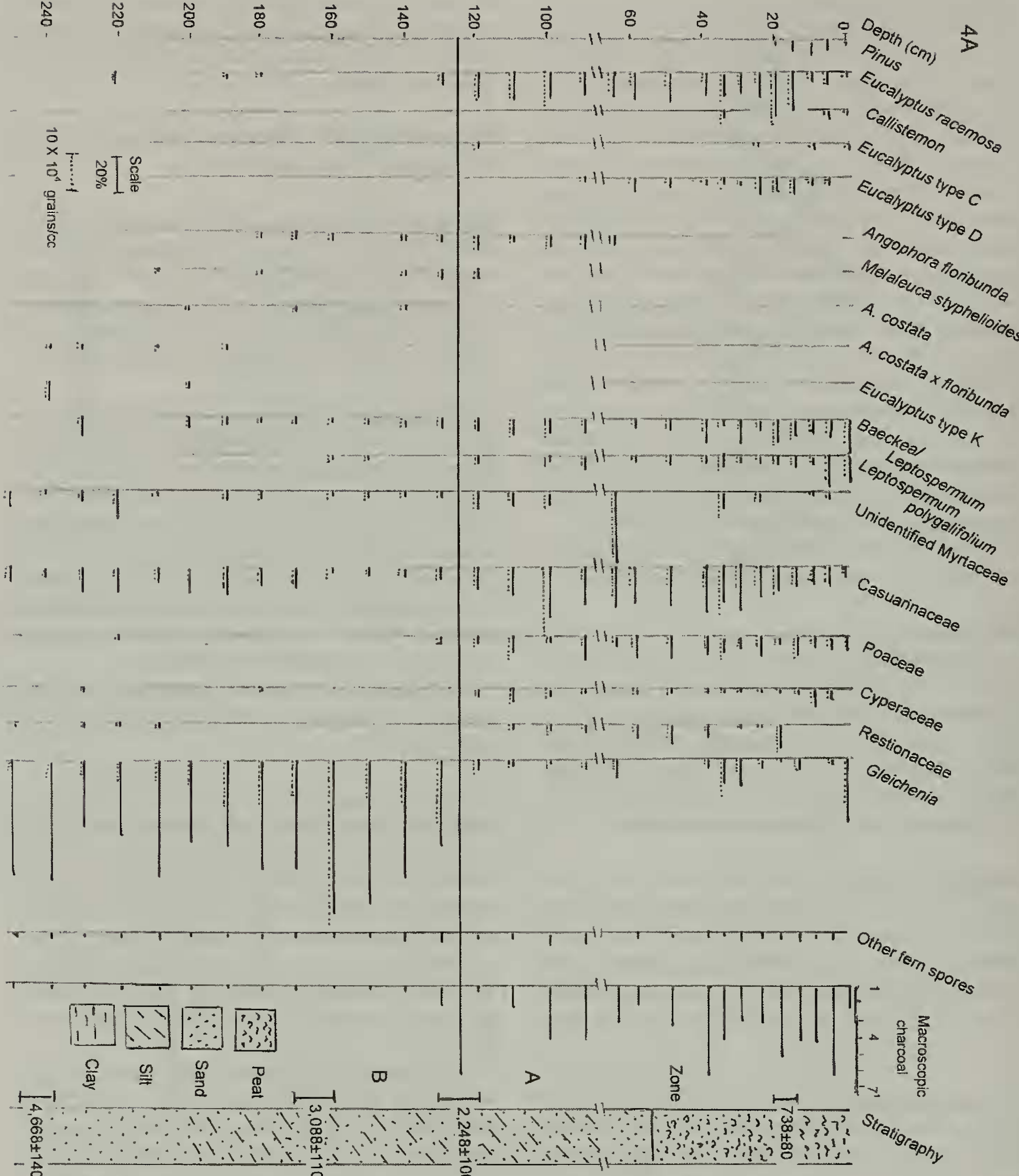
The charcoal content was consistently very low in zone B (4.7-2.2 cal ka) and higher in zone A (2.2 cal ka to present).

History of the vegetation: From about 4.7-2.2 cal ka, myrtaceous species and Casuarinaceae dominated open vegetation communities. The swamp supported abundant *Gleichenia*. About 2.2 cal ka, the tree cover of the dryland vegetation increased, with *Eucalyptus* spp and *Leptospermum* spp. becoming more diverse and abundant. Casuarinaceae was also more abundant. *Gleichenia* declined dramatically, but this change was not accompanied by any visible change in the sediments.

Fire appears to have been a rare feature of the environment when *Gleichenia* was dominant. With the change to a more diverse flora and increase of *Leptospemum* in the swamp community after 2.2 cal ka, fire was more common, particularly in the

Table 3. Radiocarbon ages for Warrimoo Oval Swamp

Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP)	Calibrated age (cal yr BP)
15-25	Peat	SUA-2603	730±80	738±80
120-130	Sandy silt	SUA-2604	2,190±80	2,248±100
160-170	Sandy silt	SUA-2605	2,880±70	3,088±110
240-250	Sand	SUA-2606	4,060±80	4,668±140



Figures 4A, 4B. Warrimoo Oval Swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.

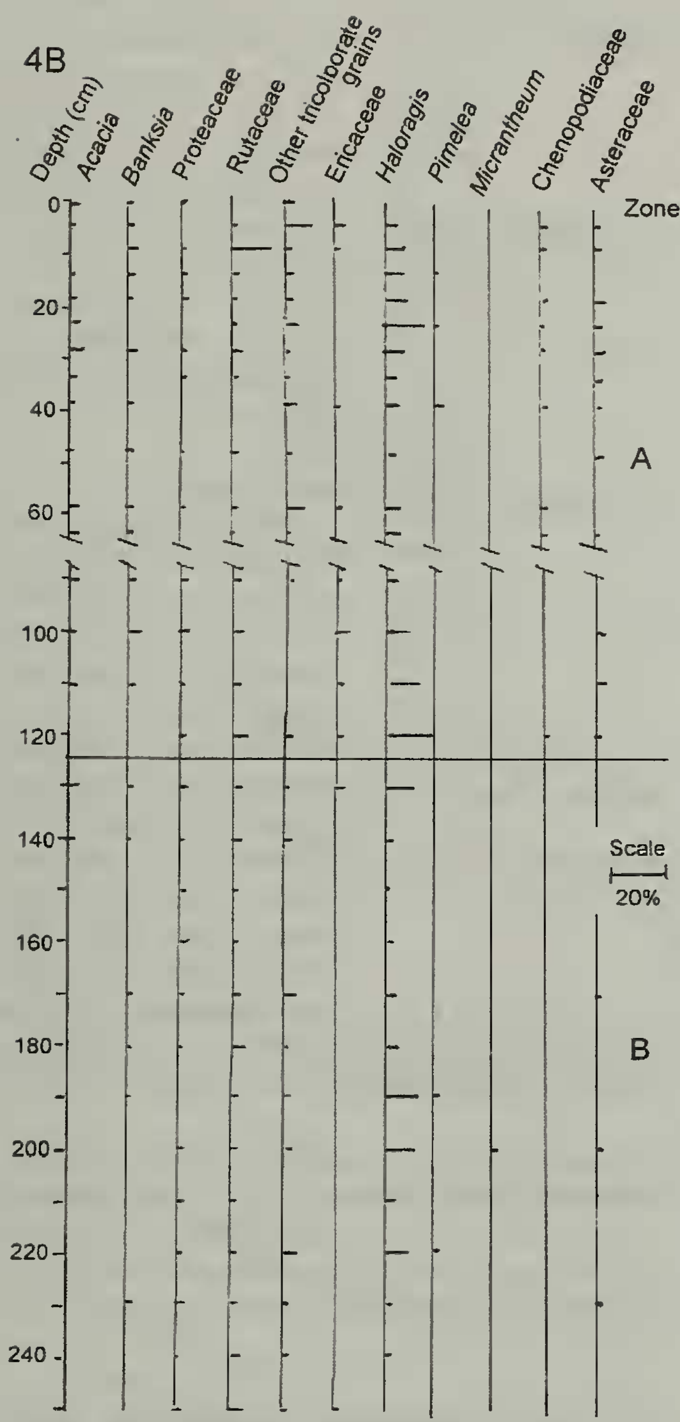


Figure 4 continued

European part at the top of the profile. There would have been a greater biomass after 2 cal ka, hence more fuel to burn, particularly on the swamp itself.

Notts Swamp

Notts Swamp, at 33° 48' 35.44" S, 150° 24' 27.66" E and about 682 m altitude is located in a shallow hanging valley. Below the swamp, Reedy Creek flows over a small cliff and follows a steep, narrow valley into the Kedumba Valley. The Wentworth Falls Claystone Member outcrops near the base of the swamp.

The lower third of the swamp is used for a market garden, but there is no sign of disturbance or weed invasion on the upper part of the swamp used for this study. There is no indication of European activities in the catchment upstream of the study site and the nearest settlement is some 7 km to the north-northeast.

Stratigraphy: The core recovered 130 cm of sediment. There was dark brown and greyish brown peat with roots down to 50 cm, then black or very dark greyish brown clay at 60-100 cm, with dark grey or light grey sandy silt at 110-130 cm. Pollen was recovered throughout the sequence, sometimes in very high concentrations. Radiocarbon ages are given in Table 4.

The swamp vegetation and surface pollen: Species of *Kunzea, Gahnia* and *Leptocarpus tenax* were dominant on the swamp. Species of *Gleichenia, Selaginella, Leptospermum*, Cyperaaceae, Juncaceae and a number of sclerophyllous shrubs were also present (Chalson and Martin, this volume). In the surface samples, Myrtaceae, Casuarinaceae and Restionaceae were well represented. There was appreciable *Pinus* pollen also. (Chalson and Martin, this volume).

The pollen record: The pollen spectra from the sediments are presented in Fig. 6A, 6B and is zoned thus:

Zone D, 110-130 cm, c. ?7,300-4,500 cal yr BP (for estimated ages, see Fig. 7). Myrtaceae pollen content was low and Casuarinaceae moderate. The *Selaginella* spore content was appreciable at the base, decreasing through the zone. The Restionaceae and Poaceae content was moderate and the lowest for the profile.

Zone C, 100-80 cm, c. 4,500-2,400 cal yr BP. The Myrtaceae, Restionaceae and Poaceae representation increased but the *Selaginella* content was much reduced when compared with the zone below, and this change coincided with a change in sediments to clay. *Gleichenia* and other fern spores increased somewhat when compared with the zone below.

Zone B, 70-30 cm, c. 2,400 cal yr BP. to ?modern. There were more identifications of the mytaceous pollen, an increase in Restionaceae and few *Gleichenia* and other fern spores when compared with the zone below. The *Selaginalla* and Cyperaceae content was minimal.

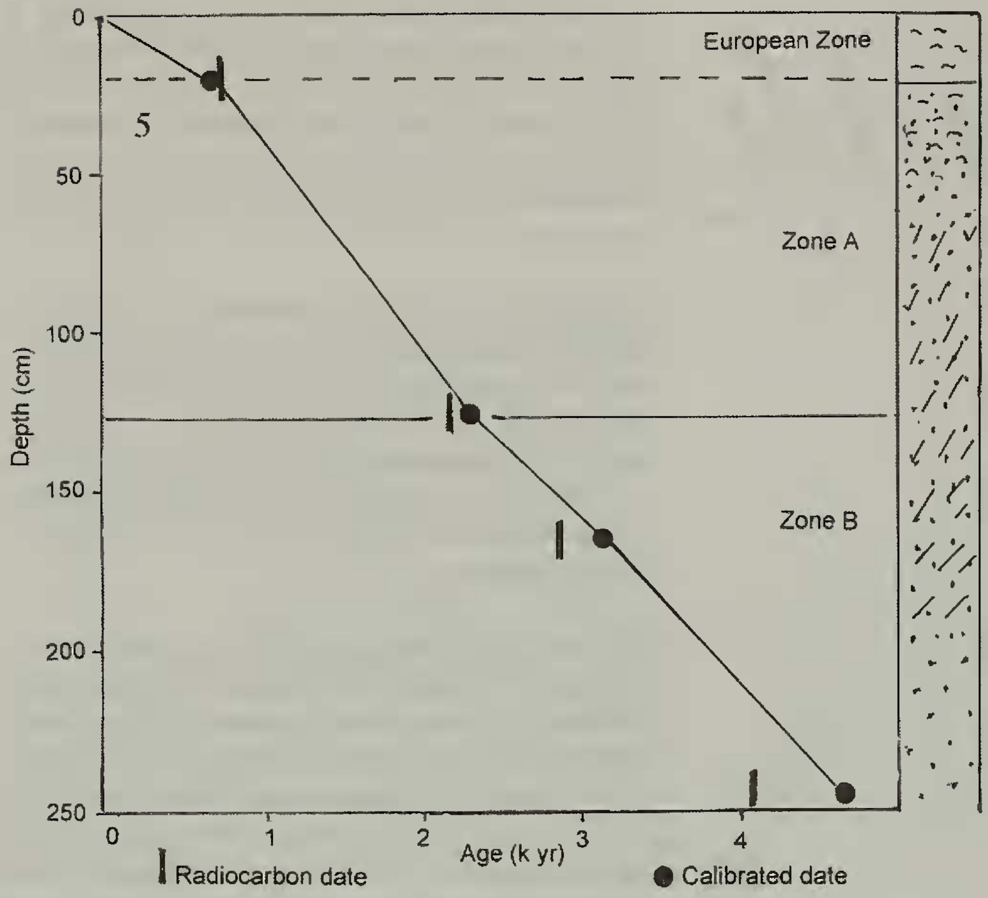


Figure 5. Warrimoo Oval Swamp summary diagram.

Zone A, 20-0 cm, modern. *Pinus* was found throughout the zone, indicating post European settlement. The Myrtaceae and Casuarinaceae pollen content was maintained. Restionaceae decreased towards the top and the Cyperaceae content, although low, is the greatest for the profile, when compared with the zones below

The charcoal content was very low at the base of the profile when *Selaginella* was prominent on the swamp, then increased after the decline in *Selagiella* and was consistently high in the European zone.

History of the Vegetation: About 7-4.5 cal ka, *Selaginella* was common on the swamp and the surrounding vegetation was an open woodland, with Casuarinaceae prominent. Fire was not common then. After about 4.5 cal ka, *Selaginella* was replaced by Restionaceae, the tree cover increased somewhat and fire became more common. The vegetation remained relatively stable until modern times when there was a slight decrease in Restionaceae and an increase in Cyperaceae. Charcoal abundance was higher when the tree cover was greater.

Ingar Swamp

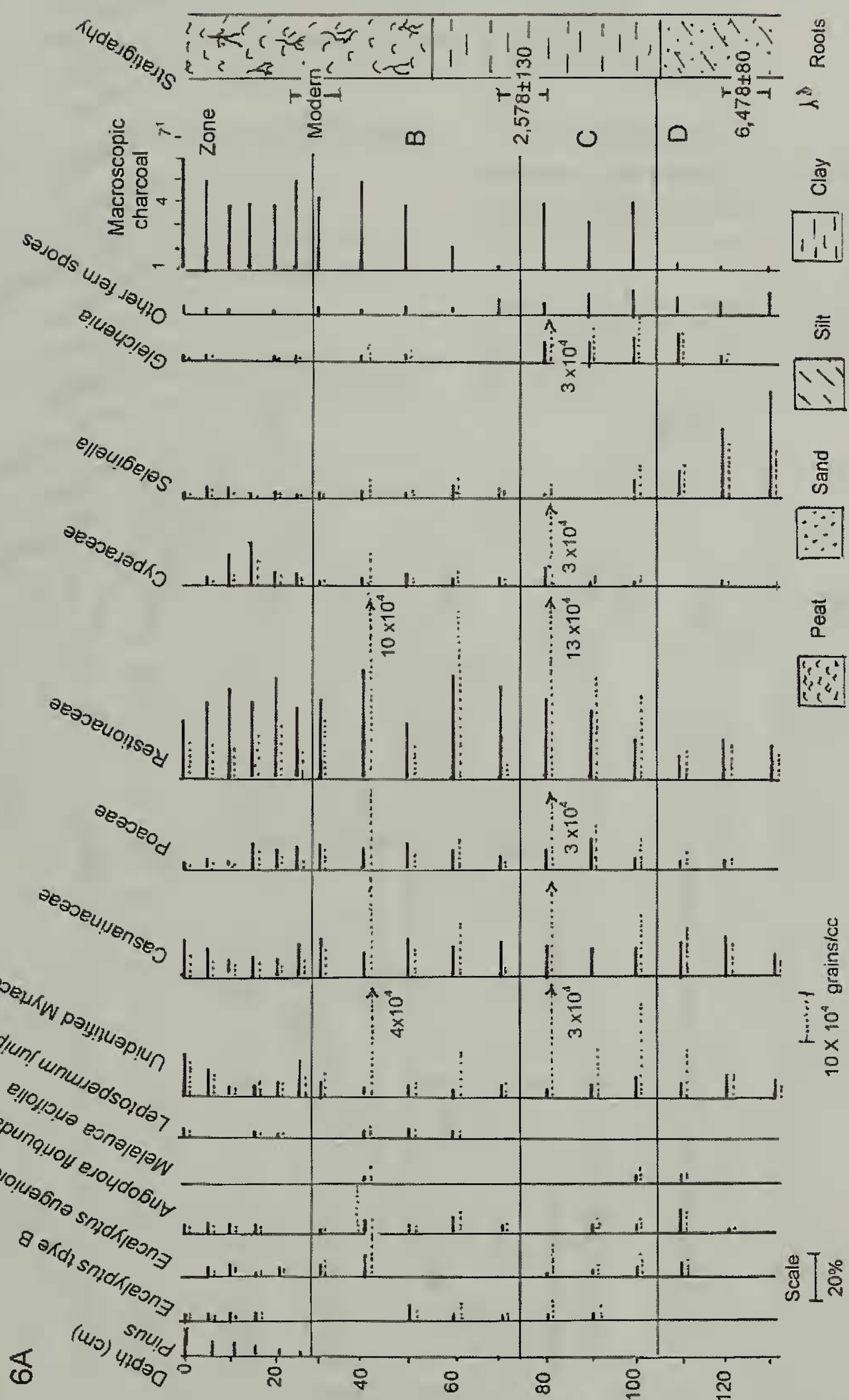
Ingar Swamp, at 33° 46' 11.65" S, 150° 27' 22.92" E and 584m altitude, is broad with many channels and hummocks of Cyperaceae forming ridges. The Banks Wall Sandstone Formation underlies the swamp and there are outcrops of the Wentworth Falls Claystone Member near the lower margin of the swamp. The swamp occupies the floor of a shallow hanging valley on the plateau surface. Below the swamp, Ingar Creek forms a waterfall where the valley gradient steepens.

Stratigraphy: The core recovered 155 cm of sediment. Peat with roots was found at 0-20 cm, then humic clay with roots at 25-110 cm, sandy humic clay at 120-130 cm, then sandy clay at 135-145cm, and silty clay at 150-155 cm. The radiocarbon ages are given in Table 5.

The swamp vegetation and surface pollen: Species of *Leptospermum*, Cyperaceae and Restionaceae were dominant on the swamp. *Gleichenia* and some sclerophyllous shrubs were also present (Chalson and Martin, this volume). The surface samples (Chalson and Martin, this volume) showed that most of the Myrtaceae pollen was

Table 4. Radiocarbon ages for Notts Swamp

Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP.)	Calibrated age (cal. yr BP.)
25-35	Peat with roots	SUA 2653	1.013±0.008x modern	Modern (<33)
75-85	Clay	SUA 2654	2,400±70	2,578±130
120-130	Sandy silt	SUA 2655	5,630±70	6,478±80



Fiuress 6A, 6B. Notts swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.

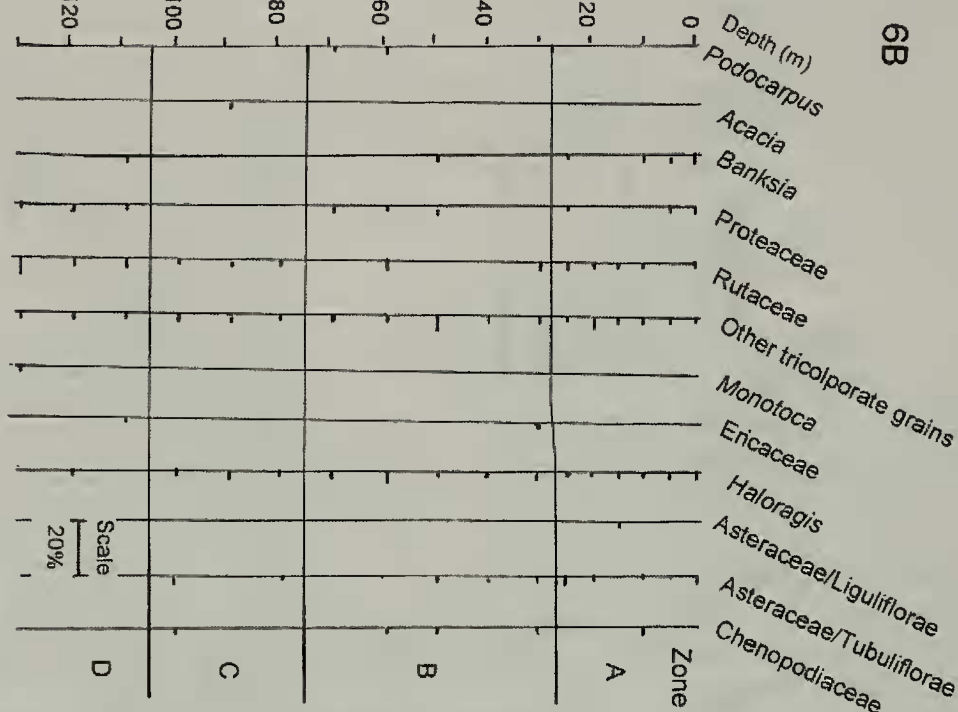


Figure 6 continued

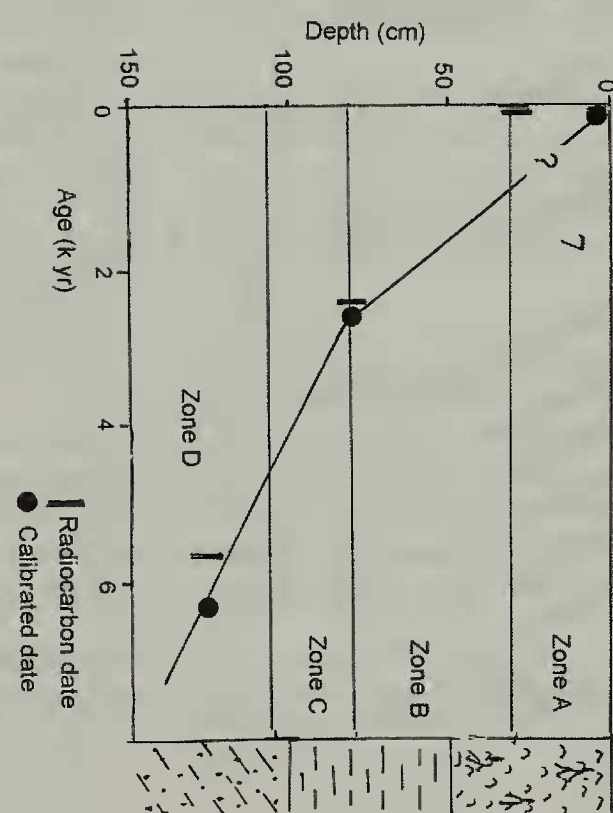


Figure 7. Notts swamp summary diagram.

Table 5. Radiocarbon ages for Ingar Swamp

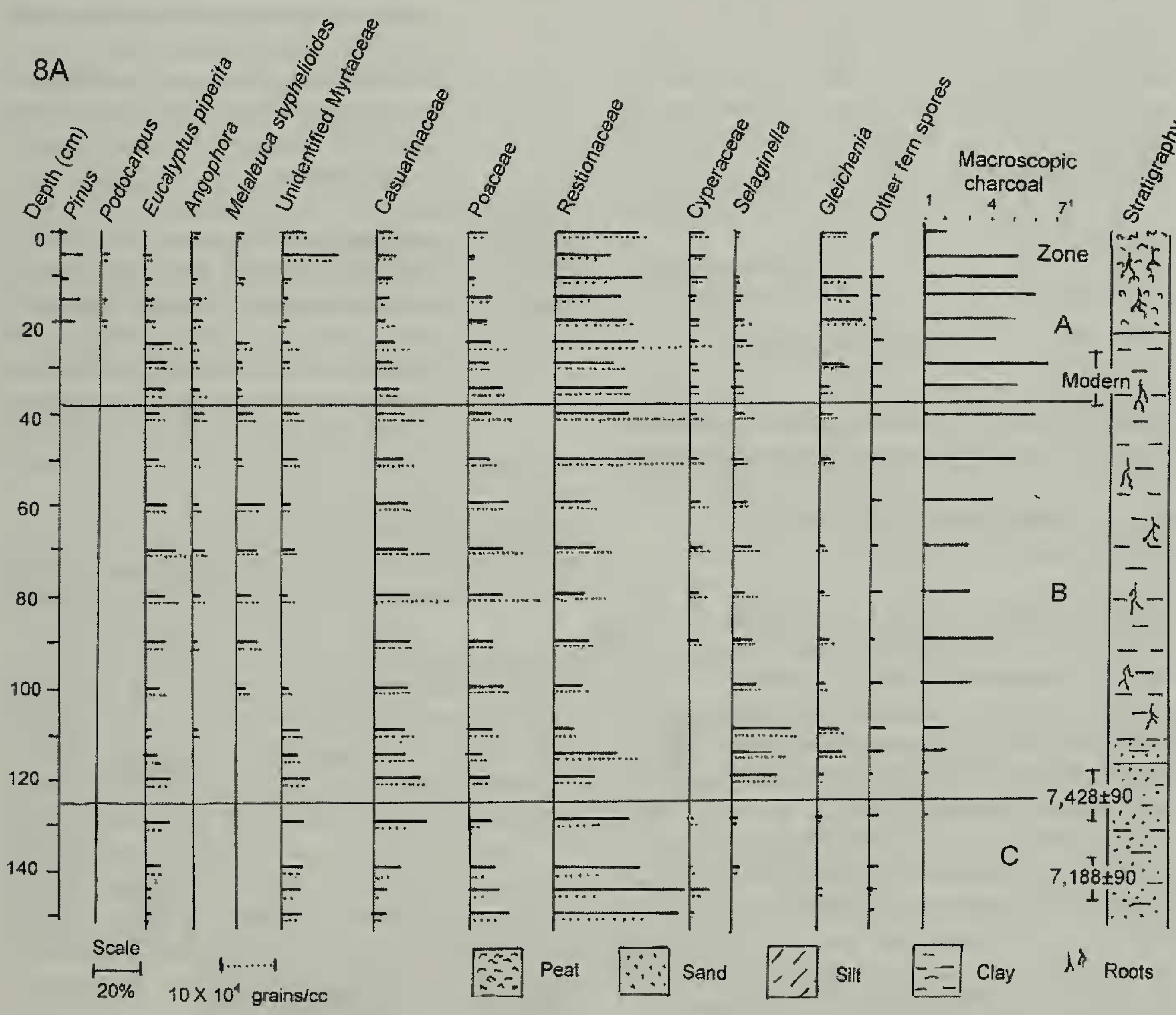
Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP.)	Calibrated age (cal. yr BP.)
30-40	Humic clay with roots	BETA 20942	105.1±0.8% modern	Modern (<43)
120-130	Sandy humic clay	BETA 20943	6,460±100	7,428±90
140-150	Sandy clay	BETA 20944	6,220±100	7,188±90

unidentifiable. There was moderate Casuarinaceae and Poaceae.

The pollen record: The pollen spectra from the sediments is shown in Fig. 8A, 8B and has been zoned thus:

Zone C, 150-130 cm, c. 7,000 cal yr BP (see Fig. 9 for estimated ages). Abundant Restionaceae marked this zone. *Eucalyptus piperita*, other Myrtaceae and Casuarinaceae were prominent and there was a moderate content of Poaceae.

Zone B, 120-40 cm, c. 7,000-?2,200 cal yr BP. There was greater diversity here and more of tree/large shrub pollen, viz. *E. piperita*, *Angophora*, *Melaleuca*



Figures 8A 8B. Ingar swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.

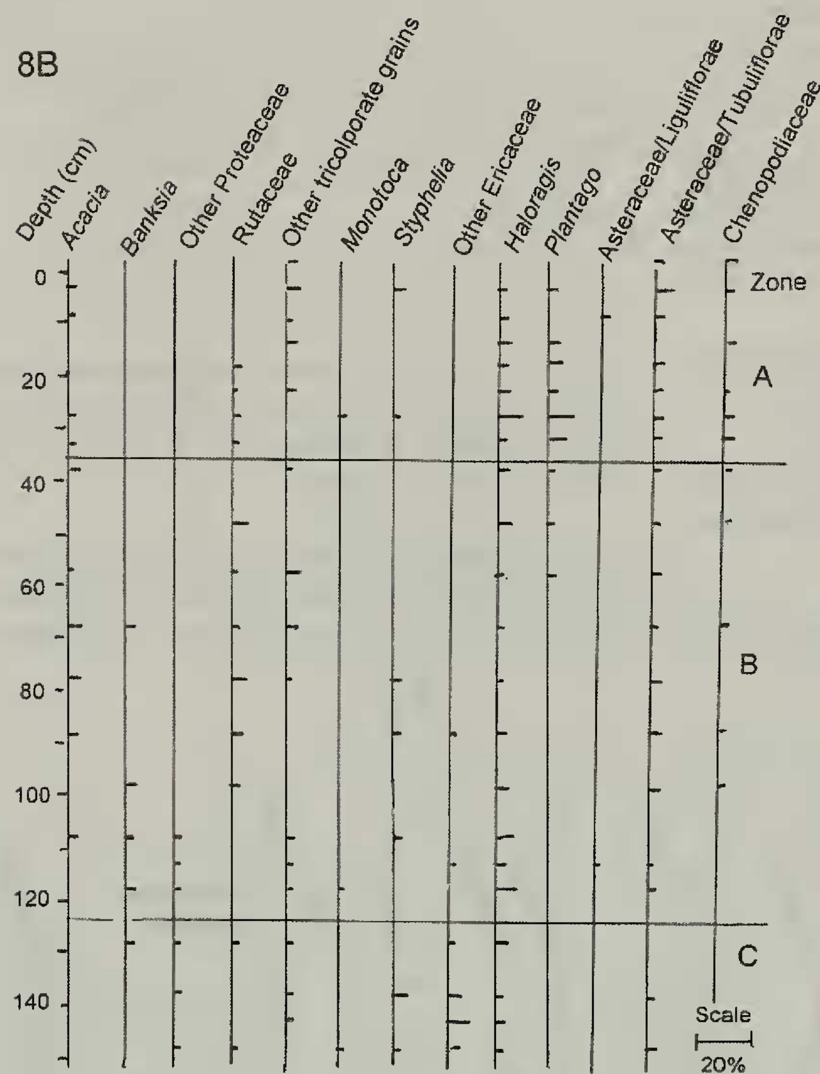


Figure 8 continued

styphelioides and Casuarinaceae, when compared with the zone below. There was a little more Poaceae but less Restionaceae than in the zone below. *Selaginella*, and to a lesser extent, *Gleichenia*, were moderate in the base of the zone.

Zone A, 40-0 cm, c. 2,200-0 cal yr BP to modern. *Pinus* was found down to 20 cm, marking European settlement. The dryland flora was similar to the zone below, but tree species declined with European influence. Restionaceae and *Gleichenia* were more abundant than in the zone below.

There was very little charcoal in the basal zone C, increasing in zone B and reaching a maximum in the European zone A.

History of the vegetation: Before 7 cal ka, the vegetation was relatively open, but after about 6 cal ka, the tree cover increased, especially Casuarinaceae. On the swamp, Restionaceae decreased but Cyperaceae, *Selagiella* and *Gleichenia* increased slightly. In the European zone, there was a slight decline in Casuarinaceae and an increase in the swamp species of Restionaceae and *Gleichenia*. Fire was relatively rare about 6 cal ka, but increased through time, to a peak in the European period.

Kings Tableland Swamp

Kings Tableland Swamp, at 33° 45' 47" S, 150° 22' 43" E and about 780-790 m altitude, is located in the floor of a steeply sloping small valley off Queen Victoria Creek. The valley floor steepens abruptly below the swamp and a waterfall cascades over a small cliff. The Banks Wall Sandstone Formation underlies the swamp and the Wentworth Falls Claystone outcrops near the base of the swamp. An area of development is found less than 1 km to the west where exotic conifers have been planted in the gardens.

Stratigraphy: The core sampled 220 cm of sediments which were peat down to 10 cm, then peaty sand at 15–20 cm, humic sand at 30-40 cm, peaty silt at 50 cm, humic sand at 60-90 cm, clay/sand at 100-120 cm and sand at 130-220 cm. Radiocarbon dates are given in Table 6.

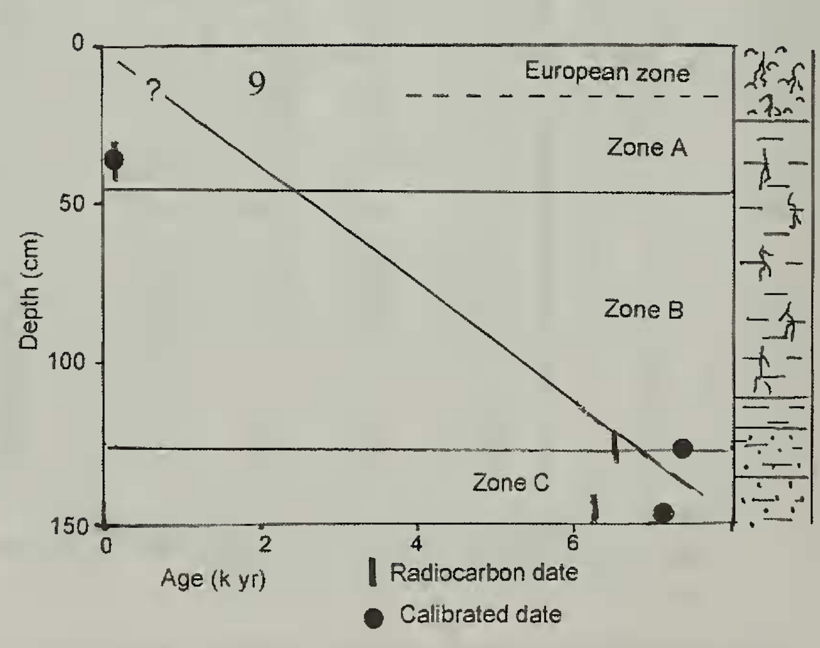


Figure 9. Ingar Swamp summary diagram

Table 6. Radiocarbon ages for Kings Tablelands Swamp

Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP.)	Calibrated age (cal. yr BP.)
15-20	Peaty sand	SUA 2656	1.045±0.008 x modern	Modern (< 33)
50-60	Humic sand	SUA 2657	1,210±70	1,208±90
80-90	Humic sand	SUA 2658	2,410±70	2,578±130
155-160	Fine sand	SUA 2659	9,040±80	10,208±130

The swamp vegetation and surface pollen: *Leptospermum* species were dominant, but *Gleichenia* and sclerophyllous shrubs were also found on the swamp (Chalson and Martin, this volume). In the surface samples, the Myrtaceae content was low but Casuarinaceae was well represented (Chalson and Martin, this volume). The swamp taxa Restionaceae, *Selaginella* and *Gleichenia* were also well represented and the introduced *Pinus* was abundant.

The pollen record: The pollen spectra from the sediments (Figs 10A, 10B) have been zoned thus:

Zone C, 200-90 cm, c. ?>12,000-3,800 cal yr B P (see Fig. 11 for estimated ages). The Myrtaceae content was low and Casuarinaceae content moderate (Fig. 10A). Sclerophyllous shrubs and Restionaceae were well represented (Fig. 10B). *Gleichenia* and other fern spores were moderate. *Eucalyptus deanei* was found in the basal part of the zone and *Banksia* in the upper part.

Zone B, 80-30 cm, c. 3,800 cal yr BP to modern. This zone had some very high pollen concentrations which mirrored the spectra of the percentages, suggesting that the high concentrations result from slow sediment accumulation rather than the increased input of any one (or more) particular pollen type(s).

The Myrtaceae pollen proportion remained low but the Casuarinaceae representation had increased, when compared with the zone below. The proportion of Restionaceae and *Gleichenia* had decreased, but Cyperaceae and *Selagiella* had increased, in comparison with the zone below. Sclerophyllous shrubs were also well represented in this zone.

Zone A, 0-25 cm, modern. *Pinus* was found here, delimiting the European zone. The myrtaceous content had increased a little, especially *Melaleuca*. Casuarinaceae and Restionaceae decreased somewhat but *Gleichenia* increased considerably, when compared with the zone below.
The charcoal content was low to moderate in zones C and B, and increasing in the modern zone A.

History of the vegetation: The dearth of myrtaceous taxa, predominance of Casuarinaceae and the diversity and relative abundance of the shrubby taxa suggests a heathland, given that the two species of Casuarinaceae found in the region today, *Allocasuarina distyla* and *A. nana*, are shrubs/small trees. The swamp flora was dominated by Restionaceae throughout, with *Gleichenia* becoming prominent in modern times. Myrtaceae remains low until modern times, suggesting the surrounding vegetation remained relatively open. The charcoal content was relatively low until modern times, suggesting less fire activity, or lesser fuel to burn, until European times.

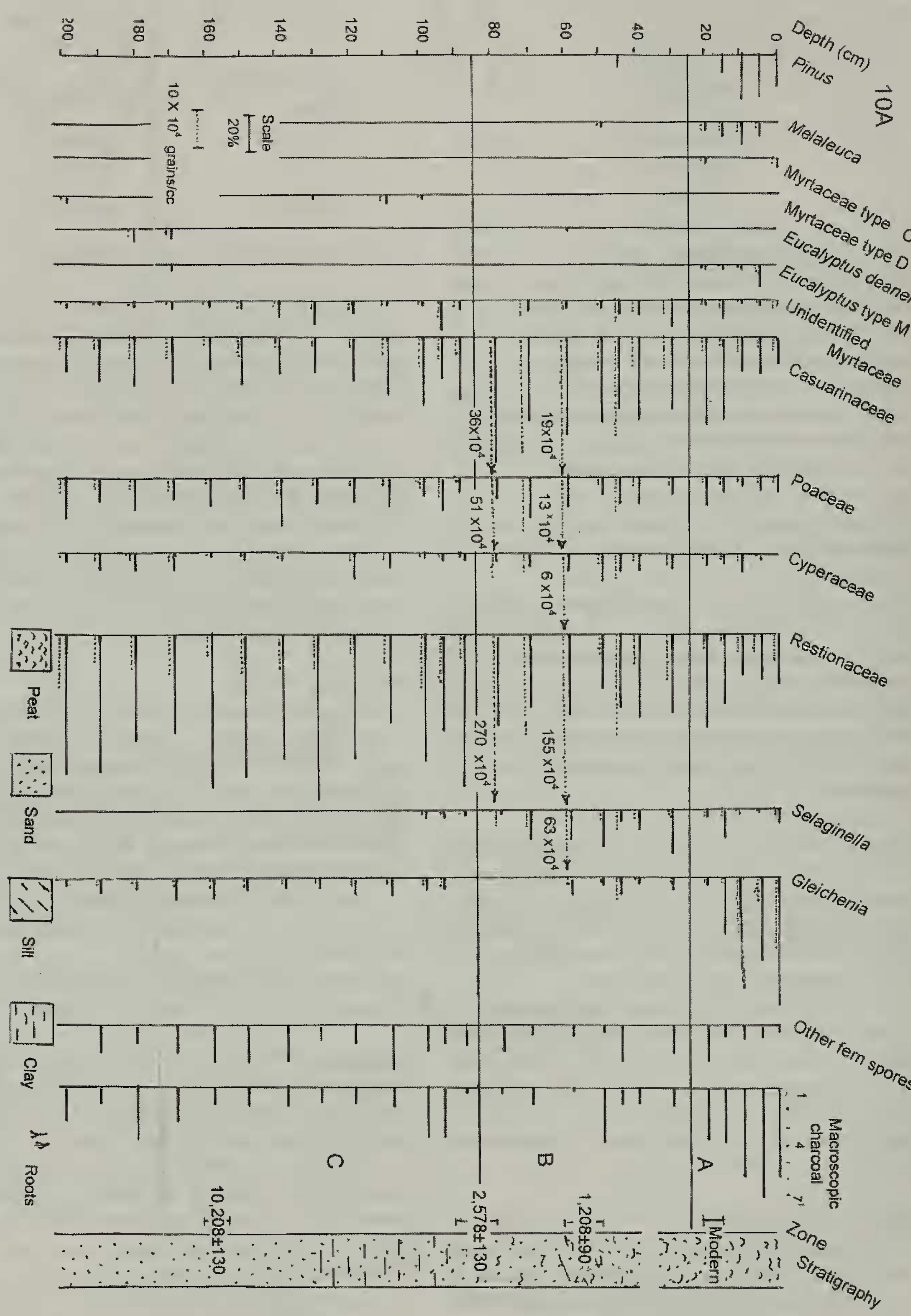
Katoomba Swamp

Katoomba Swamp, at 33° 43' 03" S, 150° 19' 18" E and 950 m altitude, is located in a small, shallow valley which is a tributary of Gordon Creek (Chalson and Martin, this volume). The Banks Wall Sandstone Formation underlies the swamp and the Wentworth Claystone Member outcrops near the base of the swamp, probably impeding drainage.

This swamp is surrounded by urban development. There is evidence of drainage ditches and a sealed road runs across the swamp. Much of it is (or has been) used for yards for light industry and horse paddocks. Housing extends to the edge of the swamp.

Stratigraphy: Two cores were necessary to recover sediments spanning the whole of the Holocene. Core 1 consisted of (1) dark greyish brown or dark brown silty clay/humic clay/clay with roots, 0-20 cm, then (2) dark greyish brown, black, or dark grey silty or sandy clay at 25-80 cm, followed by (3) dark grey sand at 85 cm, (4) dark grey clay at 90 cm, (5) dark greyish brown or dark grey sandy or silty clay at 95-115 cm, (6) dark grey sand at 120 cm and (7) dark grey sandy clay at 125-130 cm.

The stratigraphy of core 2 consisted of (1) dark greyish brown, dark grey or dark brown silty clay at 0-30 cm, then (2) dark grey or dark brown sandy clay,



Figures 10A, 10B. Kings Tableland Swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.

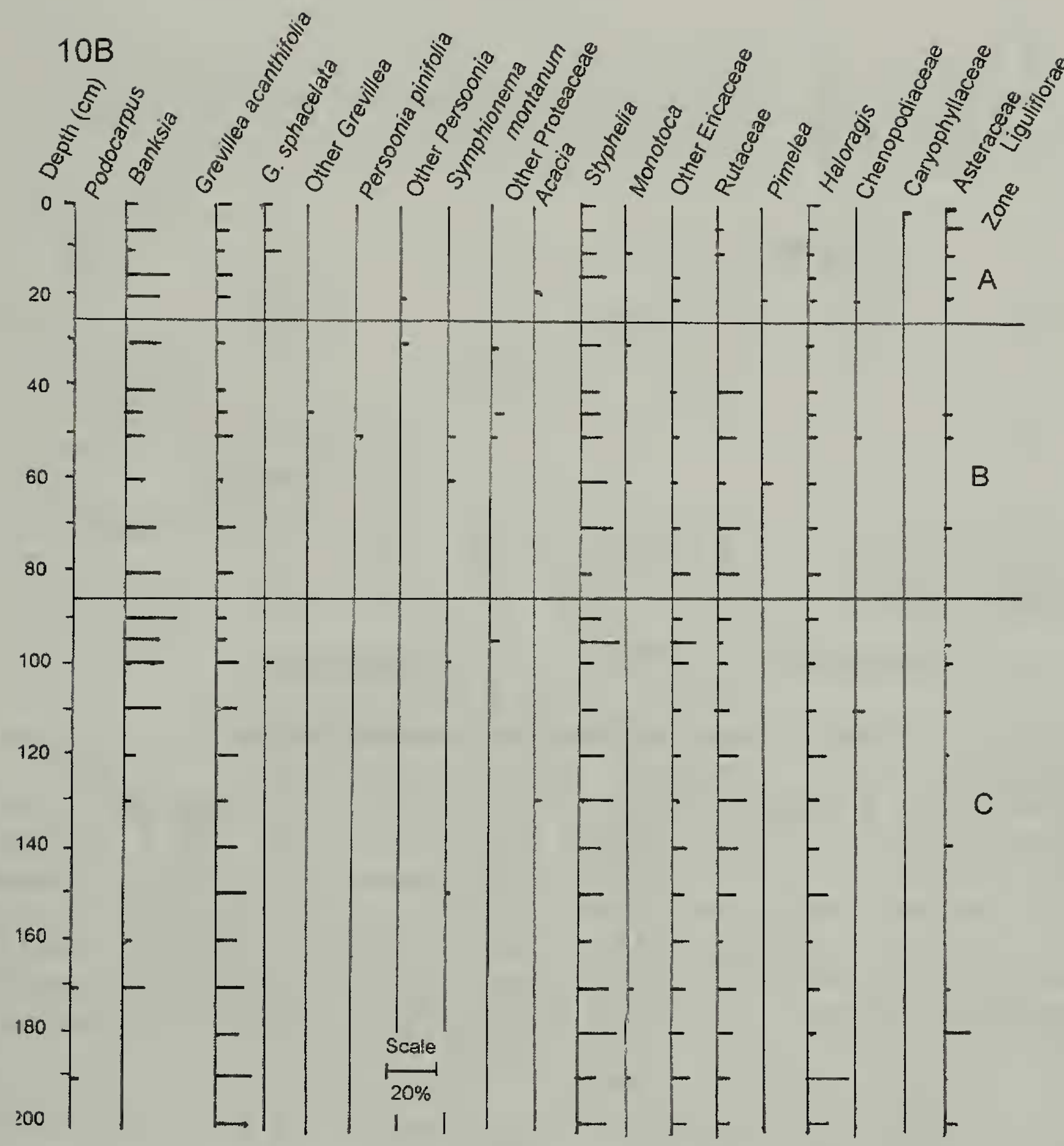


Figure 10 continued

35-40 cm, followed by (3) dark greyish brown sand at 42-48 cm and (4) dark grey clay or sandy clay at 50-55 cm. Radiocarbon dates are presented in Table 7.

The swamp vegetation and surface pollen: The moss *Dawsonia*, and species of Cyperaceae and Juncaceae were dominant on the swamp. *Kunzea* and *Leptospermum* species were also dominant and many sclerophyllous shrubs were found on the edge of the swamp, but the natural vegetation was highly disturbed here (Chalson and Martin, this volume). Poaceae (both native and introduced species) was the dominant pollen type in the surface samples, reflecting the urbanisation and the disturbance at the site. *Pinus* pollen was also present in appreciable amounts. Total Myrtaceae pollen was moderate and Casuarinaceae pollen was low. The swamp taxa, Restionaceae, Cyperaceae, *Selaginella* and *Gleichenia* were present in low proportions (Chalson and Martin, this volume).

The pollen record: Pollen recovery from the cores was good and some very high concentrations were found, especially in the clay (Figs 12A, 12B). The cores were zoned thus:

Core 2, Zone D, 55-0 cm, c. 12-11,000 cal yr BP (see Fig. 13 for estimated ages). The Myrtaceae content was low but *Eucalyptus oreades* and *E. pauciflora* had been identified. Casuarinaceae and Poaceae representation was moderate and Restionaceae was high (Fig. 12A). Asteraceae/Tubuliflorae and Ericaceae were prominent amongst the herbs and shrubs (Fig. 12B). The charcoal content was moderate throughout.

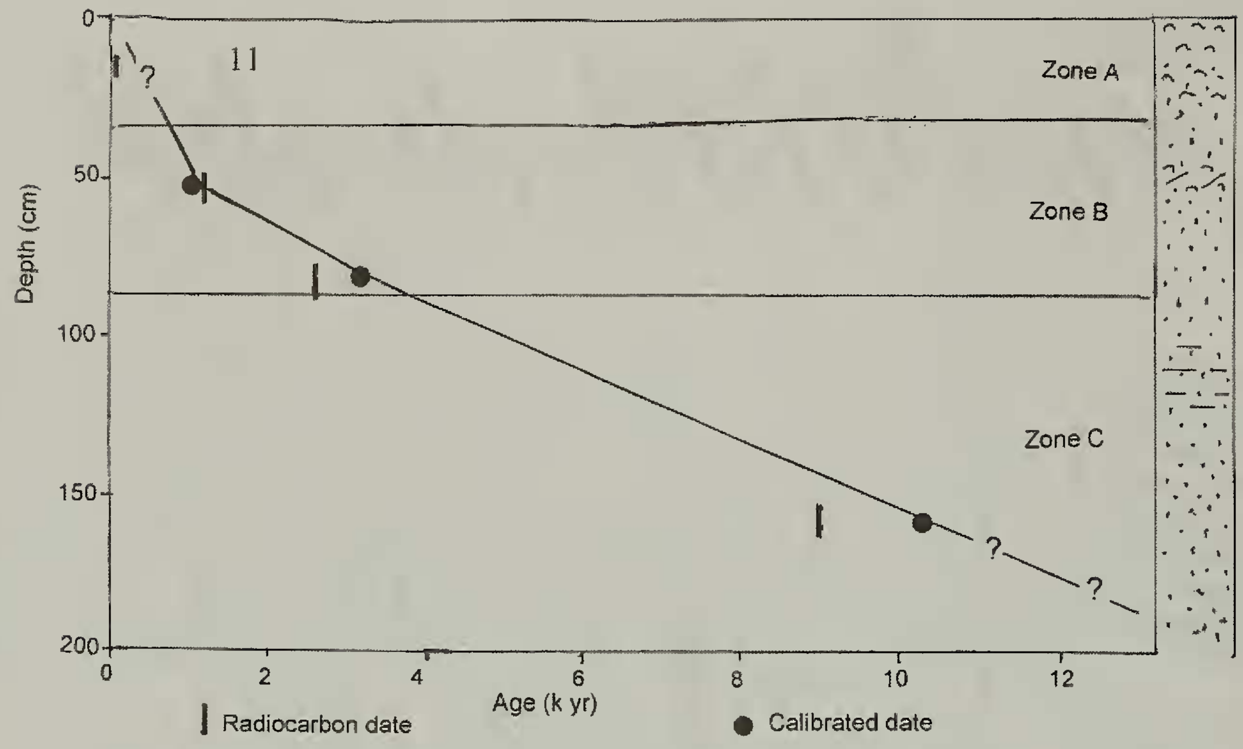


Figure 11. Kings Tableland Swamp summary diagram.

Core 1, zone C, 130-75 cm, c. 6,200-4,000 cal yr BP (for estimated ages, see Fig 13). The Myrtaceae representation was very low, lower than in the zone below, and *Eucalyptus* species were not recorded from most samples. Casuarinaceae representation was low also, Poaceae was moderate and Restionaceae high, all fairly similar to the zone below.

Core 1, zone B, 70-30 cm, c. 3,100-?1,500 cal yr BP. The Myrtaceae content had increased and *Eucalyptus oreades* was present through the zone, and this was the most notable difference when compared with the zone below. Casuarinaceae abundance was moderate and the Poaceae representation had decreased when compared to the zone below. Restionaceae abundance was a little less than in the zone below, decreasing further towards the top of the zone. *Haloragis* and *Grevillea acanthifolia* were prominent amongst the herbs and shrubs.

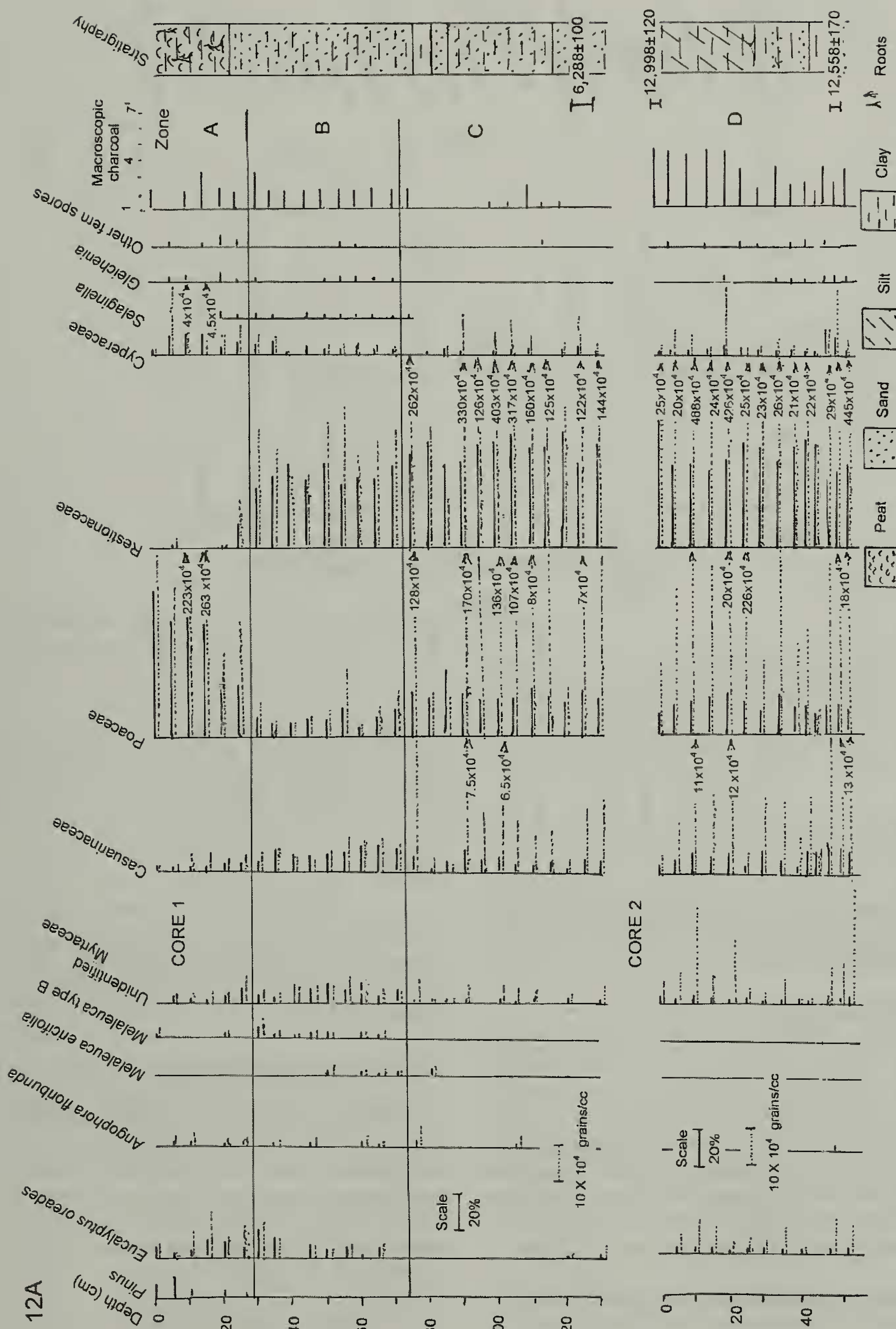
Core 1, zone A, 25-0 cm, c. ?1,500 cal yr BP to present. *Pinus* was consistently present, denoting the European zone. Total Myrtaceae and Casuarinaceae representation were low, decreasing somewhat from the base, but *E. oreades* and *A. floribunda* were found throughout the zone. Poaceae pollen increased markedly from the base of the zone but Restionaceae was very low at the very base, then virtually absent from the rest of the zone. Cyperaceae increased a little and Asteraceae/Liguliflorae was present throughout the zone.

The charcoal content was very low in zone C, then low through the rest of the core, with an occasional moderate value.

History of the vegetation: There was an open or sparse tree cover about 11-12 cal ka. By 6-5 cal ka, the site appears to have been almost treeless. About 4 cal ka, *E. oreades* returned to the site which became wooded once again. Restionaceae was dominant on the swamp and Poaceae was moderately common until 3 kyr BP, after which, both declined. In the European zone, Poaceae increased dramatically, no doubt reflecting urbanisation. At the same time Restionaceae decreased and almost vanished from the swamp. *E. oreades* remained dominant but it

Table 7. Radiocarbon ages for Katoomba Swamp

Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP)	Calibrated age (cal. yr BP)
Core 1,125-130	Sandy clay	Beta 24545	5,450±80	6,288±100
Core 2, 0-5	Silty Clay	Beta 24547	11,030±130	12,998±120
Core 2, 50-55	Sandy Clay	Beta 24546	10,570±100	12,558±170



Figures 12A, 12B. Katoomba Swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.

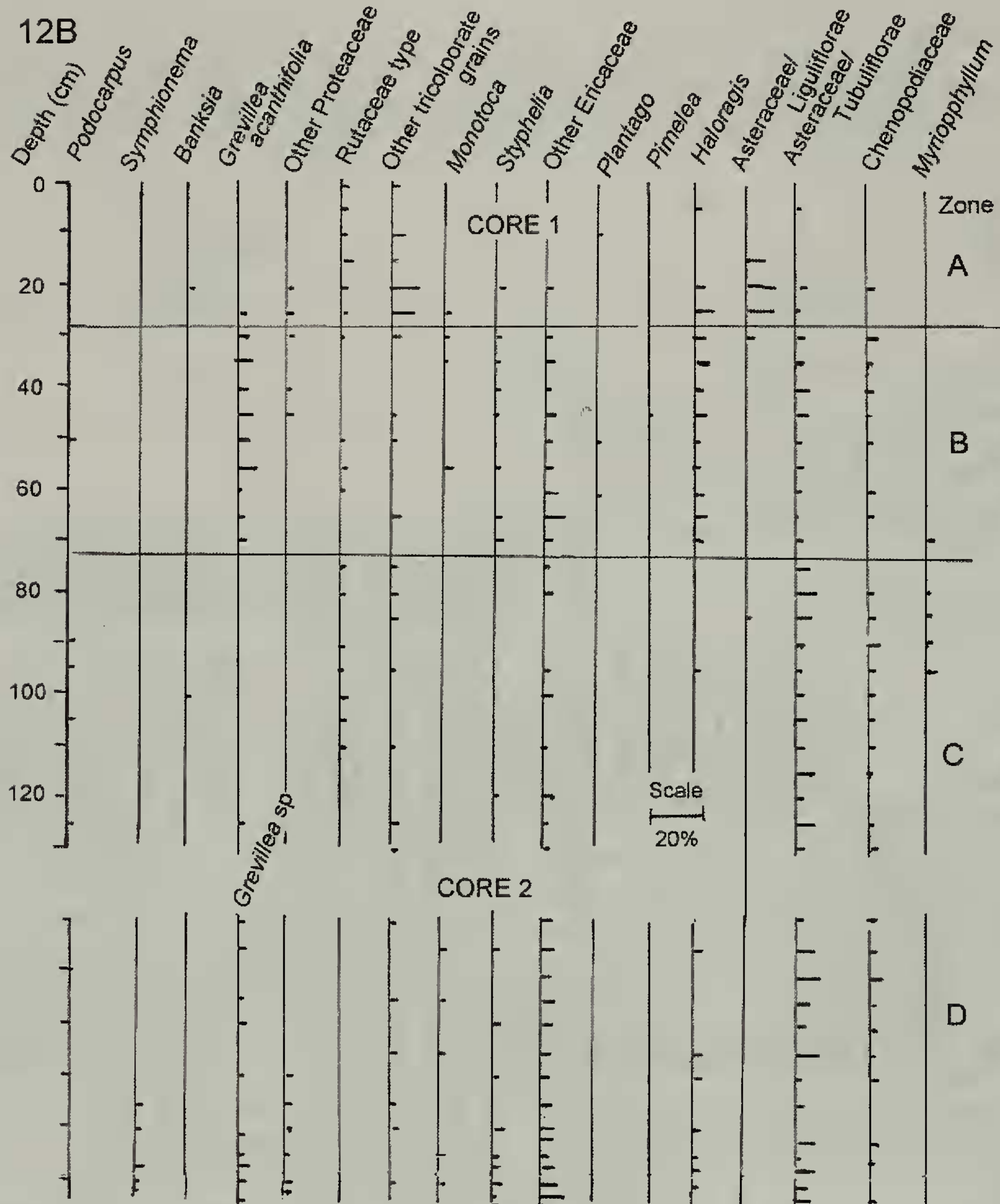


Figure 12 continued

decreased, along with Casuarinaceae in the time of the Europeans. Fire activity was low to moderate through most of the time.

Newnes Swamp

Newnes Swamp, at 33° 22' 57" S, 150° 13' 20" E and 1,060 m altitude, is located in a shallow hanging valley with pine plantations in close proximity. Regular burning maintains fire breaks for the young pine plantations. The swamp is underlain by the Burra-Moko Head Sandstone Member of the Banks Wall Sandstone Formation which has thin claystone interbeds, and it is likely that one of these clay layers impedes drainage and hence maintains the swamp.

Swamp stratigraphy: The core sampled 90 cm of sediment. Clay or peat with roots was found down to 20 cm, then sandy clay down to 35 cm, followed by sand to 55 cm, then sandy clay with roots down to 65 cm, then silty clay to 75 cm, and finally sand or sandy clay in layers to 90 cm. Radiocarbon dates are presented in Table 8.

The swamp vegetation and surface pollen: *Banksia* and *Kunzea* were dominant and *Baeckea*, *Leptospermum*, other sclerophyllous shrubs, Cyperaceae and Poaceae were also present on the swamp (Chalson and Martin, this volume). There was appreciable Myrtaceae pollen in the surface samples, but Restionaceae and *Gleichenia* were dominant in the surface pollen spectra. *Pinus* was present but not abundant. (Chalson and Martin, this volume).

The pollen record: Pollen recovery from the core

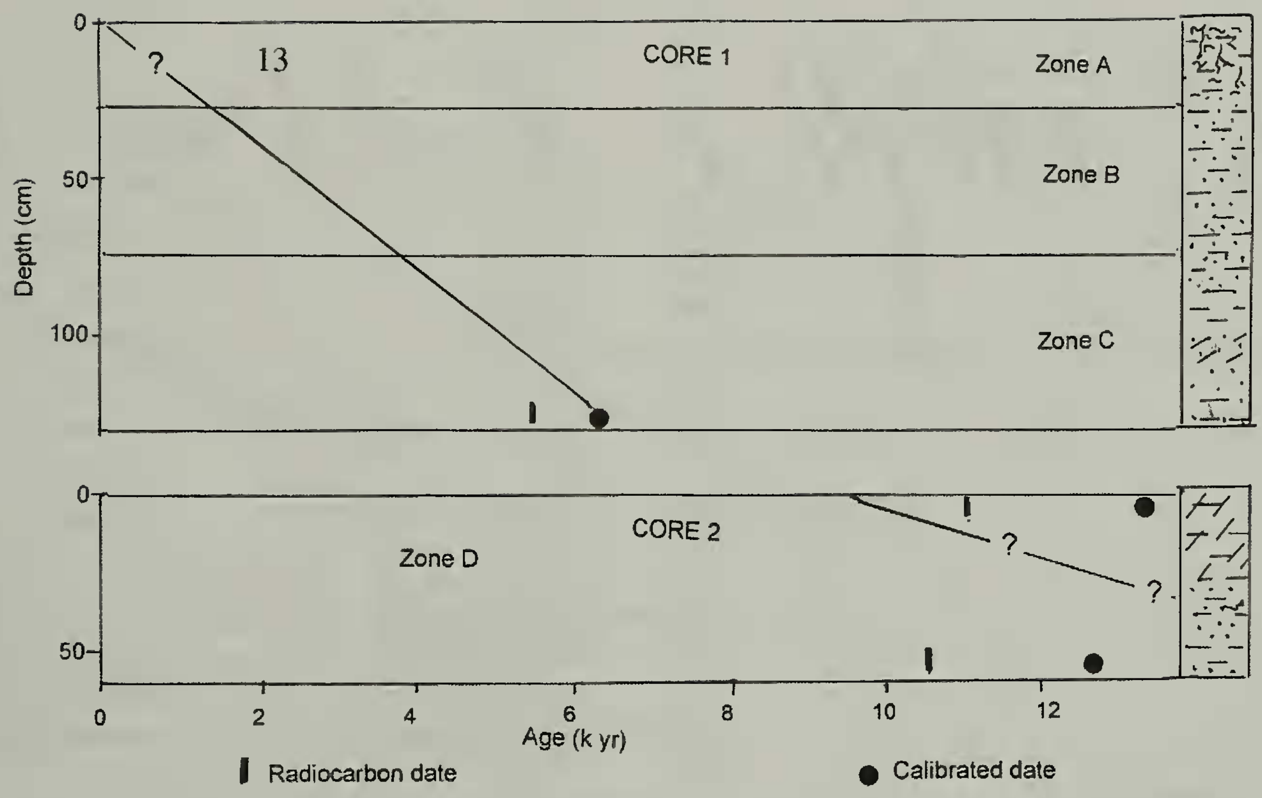


Figure 13. Katoomba Swamp summary diagram.

was good and there was some exceptionally high concentrations, especially in the clay at 60-70 cm. The core was zoned thus (Figs 14A, 14B):

Zone D, 90-55 cm, c. 11,000-7,5 00 cal yr BP (see Fig. 15 for estimated ages). Myrtaceae pollen was low, but *Eucalyptus pauciflora/rubida* had been identified. Casuarinaceae was also low at the base of the zone, increasing upwards (Fig 2A). Asteraceae/ Tubuliflorae and Chenopodiaceae were prominent amongst the herbs and shrubs (Fig. 14B). Poaceae and Restionaceae were well represented.

Zone C, 50-40 cm, c. 7,500-1,800 cal yr BP There was very little Myrtaceae pollen, with only one record of a *Eucalyptus* species. Casuarinaceae pollen increased, *Haloragis* was moderate and Poaceae and Restionaceae were reduced when compared with the preceding zone.

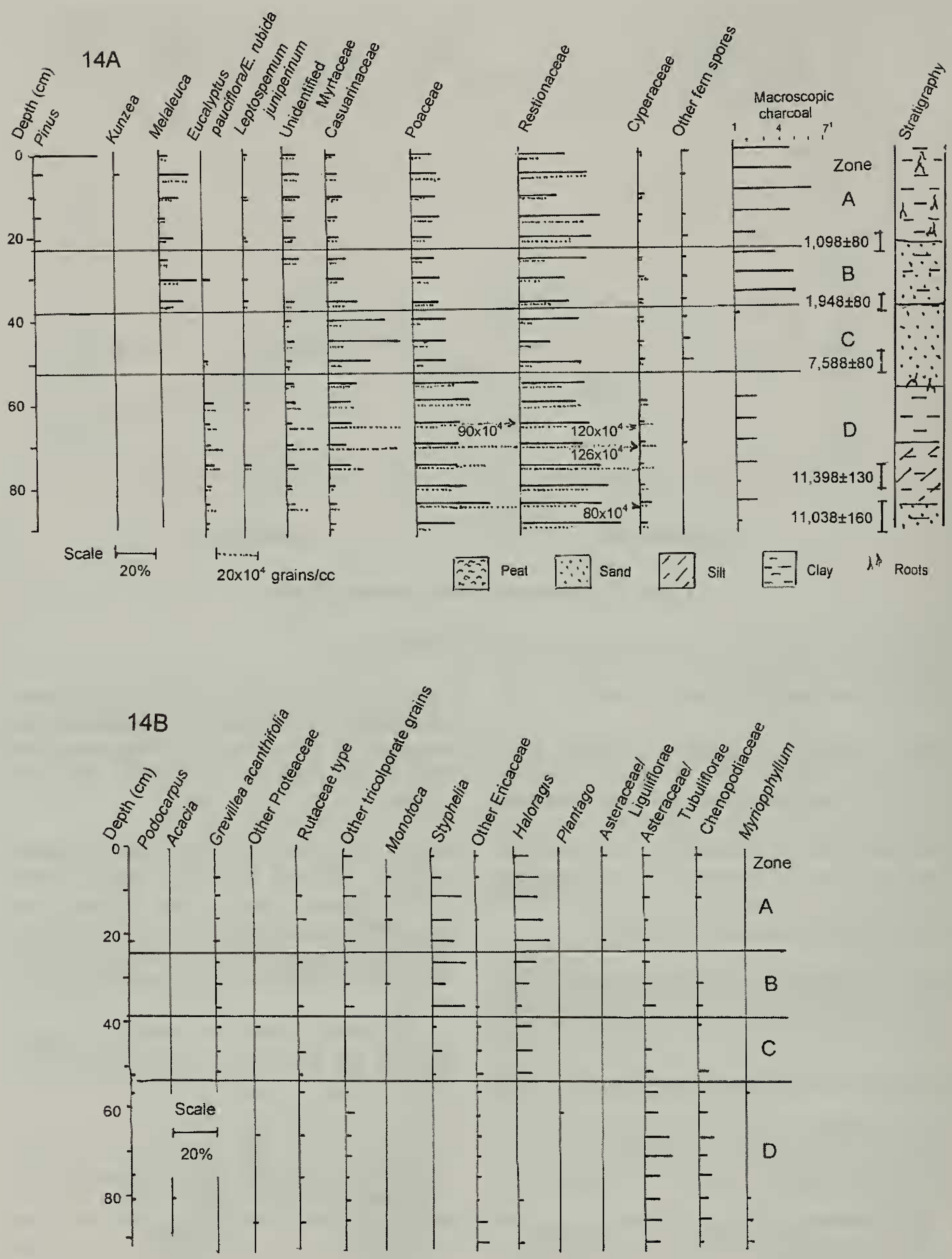
Zone B, 35-25 cm, c.1,800-?1,000 cal yr BP. *Melaleuca* representation was significant, Casuarinaceae had decreased, the shrubs were well represented, and Poaceae and Restionaceae remained low when compared with the previous zone.

Zone A, 20-0 cm, ?1,000 cal yr BP to present. *Melaleuca* continued to be the most significant of the Myrtaceae, *Styphelia* and *Haloragis* were appreciable, Poaceae remained low and Restionaceae was somewhat greater than the zone below. *Pinus* was present throughout the zone, denoting European activity.

The charcoal content was moderate in zone D, extremely low in zone C, and moderate to high in zones B and A.

Table 8. Radiocarbon ages for Newnes Swamp

Depth (cm)	Material dated	Laboratory no.	Radiocarbon years (yr BP)	Calibrated age (cal. yr BP)
20-25	Sandy clay	SUA 2648	1,090±70	1,098±80
35-40	Sandy clay	SUA 2649	1,930±70	1,948±80
50-55	Sand	SUA 2650	6,650±100	7,588±80
77-83	Silty clay	SUA 2651	9,820±90	11,398±130
87-93	Sand	SUA 2652	9,640±80	11,038±160



Figures 14A, 14B. Newnes Swamp pollen spectra. For probable source of the pollen type in the vegetation, see Appendix.

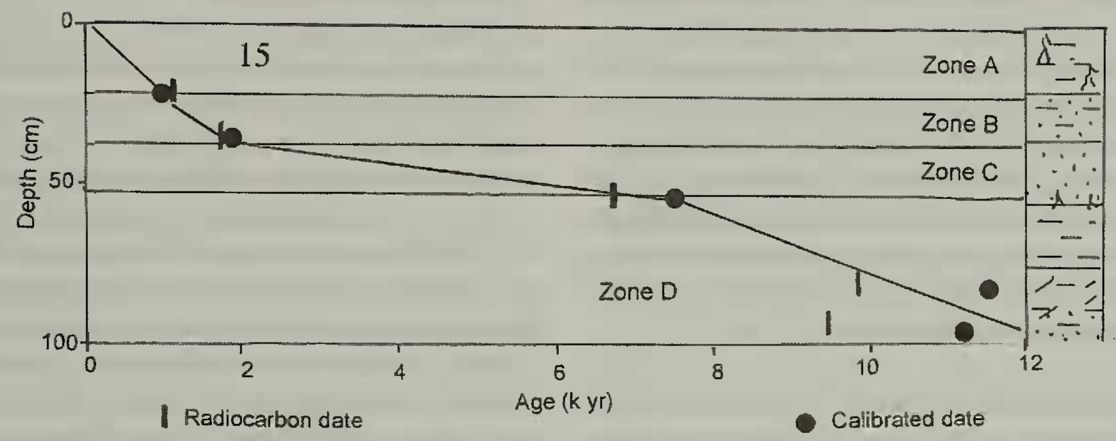


Figure 15. Newnes Swamp summary diagram.

History of the vegetation: The vegetation was open *Eucalyptus* woodland at 11 cal ka, but by about 7.5 cal ka, *Eucalyptus* species had disappeared, Casuarinaceae and the sclerophyllous shrubs increased, suggesting a heathland. After 2 ka, *Melaleuca* became prominent, possibly around or on the swamp. Burning was moderate to low in the early Holocene, very low in the mid Holocene when the vegetation was a shrubland or heath and after 2 ka, it was moderate to high, when *Melaleuca* had colonised the swamp.

DISCUSSION

Stratigraphy

All of the swamps chosen for this study are found associated with small streams in valleys of the rugged terrain of the Blue Mountains. While such sites may not be the first preference for palynology, they allow study in an area where the more favoured sites are rare. These small valley swamps rely on some barrier, often a clay substrate, to impede drainage and maintain the swampy conditions. The root mats of the vegetation stabilise the sediments and slow down the water flow, but if the vegetation is disturbed, then the sediments are prone to erosion. The swamps dry out occasionally but not seasonally. The vegetation can withstand mild or short droughts, but prolonged, severe droughts such as has been experienced in recent years destabilise the communities as some species die and others replace them. The swamps then become very vulnerable to fire, human trampling or even the next major rainfall event. Elimination of the vegetation cover over even a small area of the swamp leaves it vulnerable to subsequent erosion.

If the vegetation is destroyed and there is erosion, channelised water and higher energy flows deposit coarser grained sediment, such as sand. Eventually the vegetation re-establishes and stream flow slows down and finer particles, such as silt and clay are deposited.

It has been assumed that the sediments were deposited at a uniform rate: however, the resolution of dating does not allow this to be tested. Uniform rates of sedimentation are probably not the case at finer scales of resolution.

The peat layer at the top of the swamp is usually only 20 cm or less in thickness. While roots of the present vegetation may penetrate to a considerable depth, a discrete layer with roots at depth in some profiles suggests former peat or vegetation layers that have been buried, and the decay of most of the organic matter as the sediments accumulated. Also, there may be an appreciable humic content of the sediments at depths in the profile, a further indication of decayed vegetation.

Using the above description of the dynamics of the swamps, the sediments are interpreted as follows:

Burralow Swamp: There is only some 1.2 cal ka represented here, with sand at depth, then grading to clay and peat at the top. The rate of accumulation of the sand was rapid, with the clay and peat accumulating much slower (from Fig. 3). It is likely that the whole of this profile post-dates an erosive event.

The two basal two dates are puzzling, given that they do not conform to the uniform sedimentation rate discussed above. They are within the sand layer, which was carbon poor, and it is possible that groundwater carrying humic acids could have contaminated the sediments with younger organic matter, overwhelming the small quantities of older carbon.

Warrimoo Oval Swamp: A basal sand layer dating to about 4.7 cal ka grades into sandy silt, then another sand layer at about 1.2-1.5 cal ka. The sediments then became increasingly peaty towards the top. Deposition of the basal sand layer probably followed an erosive event, and the sand layer at 50-90 cm probably represents another erosive event. This latter layer may correlate with the basal sand layer in Burralow Creek (from Figs 3 and 5), but this hypothesis requires additional dating control to test it.

Notts Swamp: About 7 cal ka are recorded here (Fig. 7). The basal sandy silt layer is overlain by clay, with peat with roots above it. The profile appears to reflect a low energy depositional environment throughout. The stratigraphy suggests that the lower and upper layers may have accumulated at a somewhat faster rate than the clay in the middle.

Ingar Swamp: This profile also represents about 7 cal ka (Fig. 9). Sandy clay formed the basal sediments, with clay with roots above it, then peat with roots forming the top most layer.

Kings Tableland. Over 10 cal ka, the majority of the Holocene is represented here (Fig. 11). There is a basal sand layer, then a complex stratigraphy of clay, sand, silty peat, sand and sandy peat above it. This suggests that conditions of deposition would have fluctuated, and in which case is unlikely that the sequence is continuous.

Katoomba Swamp. Over 6 cal ka are represented in core 1 and 10-12 cal ka in core 2 (Fig. 13). There are no large sand layers similar to those seen in sediments at some of the other sites, but a complex stratigraphy of finer sediments, often with a sandy component.

Newnes Swamp. About 12 cal ka is recorded here (Fig. 15). The sediments are sand then sandy or silty clay in a complex stratigraphy at the base of the profile. Above this, there is a prominent sand layer, then sandy clay and peat with roots at the top. Superficially, it appears that the sand layer in the middle of the profile accumulated very slowly (Fig. 15), but another interpretation is possible. The date at the top of this sand layer is about 1.3 ka, which approximates the date of the top of the sand layers seen in Warrimoo Oval Swamp and Burralow Creek Swamp. If the sand layer does represent the aftermath of an erosive event, then a section of the sediment profile is likely to have been lost. The roots in the sandy clay at the base of the sand layer may indicate the base of a peat or vegetation layer that was buried by the accumulating sand.

Each swamp thus has its own history of sedimentation. Sandy layers in three of the swamps suggest erosion after disruption of the vegetation, sand deposition, then stabilisation sometime about 1.2-1.6 ka, with subsequent re-establishment of the vegetation and deposition of fine-grained sediments.

If fire was the cause of this erosion, then we could expect evidence of it in the charcoal record, but there is no evidence of increased charcoal at this time. Absence of charcoal cannot be taken as evidence of no fire, as erosion may well have removed the charcoal, along with some of the sediments. Fire is not the only likely cause: as discussed, prolonged drought could also destabilise these systems. Minor tectonics along fault lines in the Blue Mountains (Bembrick et al, 1980) would also accelerate erosion.

The three swamps which have this sand body are Newnes, Burralow Creek and Warrimoo Oval. Newnes and Burralow Creek are the two most northerly swamps and Burralow Creek and Warrimoo Oval are the two most easterly swamps. Whatever the cause of this disturbance, it seems to have come from or been concentrated in the north east (see Fig. 1). That Burralow Creek Swamp has only 1 ka of sediment suggests that it may have suffered the greatest disturbance and erosion.

History of the vegetation

The swamp vegetation. The survey of the vegetation (Chalson and Martin, this volume), shows that species of Restionaceae, Cyperaceae, *Gleichenia*, *Selaginella*, *Baeckea*, *Kunzea* and *Leptospermum* dominate the vegetation cover of these swamps. Many of the common sclerophyllous shrubs have been recorded on the swamps, though not dominant, as well as in the dryland vegetation (Chalson and Martin, this volume). Poaceae has both dryland and swamp species (Sainty and Jacobs, 1981).

In the pollen diagrams, *Gleichenia* and *Selaginella* are found predominantly where the sediments are sandy and Restionaceae is dominant on the clayey sediments. There is very little Cyperaceae here, unlike other sites, e.g Lake Baraba (Black et al., 2007), Dry Lake, (Rose and Martin, 2007), Mountain Lagoon (Robbie and Martin, 2007) and Penrith Lakes (Chalson and Martin, 2008) which have more Cyperaceae than Restionaceae. The swamps of this study, however, are more ephemeral and unlike the others with more Cyperaceae, which are lakes or lagoons where the water would be more permanent. Indeed, there are many species of Cyperaceae that are aquatic (Sainty and Jacobs, 1981) whereas species of

Restionaceae are found more in damp and swampy places. Thus Cyperaceae flourishes in the more permanently wet swamps and Restionaceae is more abundant in these swamps subjected to irregular drying. Species of both families may be found in the dryland vegetation but the pollen record is heavily dominated by the wetland species.

Baeckea, Kuzea and *Leptospermum* species are present in the pollen diagrams of the swamps, but mainly towards the top and especially in the European zone. There is very little pollen of these taxa at depths in the profiles. Some *Melaleuca* pollen is present and it shows much the same trends. Although the trend to more of these shrubs started before European settlement, it appears that these woody shrubs, which are often dominant on the swamps today, have probably been further encouraged by European activity, probably by the altered fire regime (Kohen, 1995).

The swamp vegetation thus reflects the sediment substrate and hydrological conditions, with some changes due to European activity.

The dryland vegetation. The sites are examined in a time sequence to determine if there has been any synchronous changes in the vegetation across the Blue Mountains.

Three sites record the early Holocene of 10 ka to 6 ka: Kings Tableland, Katoomba and Newnes Swamps. About 10 cal ka, *Eucalyptus* species were present at all three sites, but there was very little at Kings Tableland. Casuarinaceae, the other group which could be either trees or shrubs was present also. Thus all three sites appear to have been wooded in the early Holocene, with Kings Tableland probably more open than the other sites. By 6-4 cal ka, the mid Holocene, there were virtually no *Eucalyptus* in any of the sites. The vegetation had become more open and probably more of a sclerophyllous shrubland or heath. *Eucalyptus* returned to the Katoomba site about 3 cal ka, but very little is recorded in Newnes and Kings Tableland up to the present. The Katoomba swamp is located in a narrower and steeper valley than the other two sites, and this shelter may have produced better moisture retention and hence tree regeneration. *Melaleuca* became established at Newnes about 1.3 cal ka.

Two sites date from about 6 cal ka, the mid-Holocene: Notts and Ingar Swamps. Species of *Eucalyptus* and *Angophora* were present at both sites, hence they were probably wooded at the time that Kings Tableland, Katoomba and Newnes were dominated by shrubs. Warrimoo Oval dates from about 4 cal ka, and the relatively low frequencies of *Eucalyptus* and *Angophora* indicate it was an open woodland at that time.

In the period 4-2 cal ka, there was little change from the previous period at Notts and Ingar Swamps. At Kings Tableland, Casuarinaceae increased but there was still no *Eucalyptus*. At Katoomba, *Eucalyptus* and *Angophora* species reappeared, as this site probably gained an overstorey of trees again. At Newnes, the 4-2 cal ka period was similar to that before, with very little *Eucalyptus*. Burralow Swamp dated from 1 cal ka was initially very open, with the tree cover increasing about 0.8 cal ka. Except for an increase in *Melaleuca* or *Leptospermum* species in some of the swamps, there was relatively few changes after 2 cal ka until the European period,

In the European zone, there was minimal or no decline in the *Eucalyptus* and *Angophora* content. Casuarinaceae content declined noticeably at all the sites. At Burralow, Warrimoo Oval and Kings Tableland, the woody shrubs *Callistemon*, *Baeckia, Leptospemum* and *Melaleuca* increased. The Poaceae content remains unchanged in all swamps except for Katoomba, where there is a dramatic increase.

There is thus relatively little change in the palynology after European settlement in all of the sites, except at Katoomba. This perhaps reflects the relatively minor European changes to the sites, with the exception of Katoomba where the swamp itself has a history of use for various urban activities. Agricultural development has been minimal, reflecting the poor soils. The general lack of decline in tree species is unexpected, but European development has largely been confined to the ridgetops and extensive natural vegetation is a feature of the Blue Mountains. The wood of Casuarinaceae was prized by Europeans as the firewood of choice for bakeries and the timber had many uses (Entwisle 2005), hence it may have been sought out more than the *Eucalyptus* species.

Each site has its own distinctive history, as are the dominant *Eucalyptus* species at each site (Chalson and Martin, this volume). There is limited synchronicity of change between the swamps. The three swamps at the highest altitude are the oldest, dating to the beginning of the Holocene. They were wooded in the early Holocene, but became very open or almost treeless by the mid-Holocene. The sites at the lower altitudes, however, were wooded during the mid-Holocene. By the late Holocene, all of the sites had become wooded, although the tree layer may have been very open in some of them. Clearly, the interplay of many environmental factors, not the least of which is altitude, have influenced the vegetation at each site.

Other sites in the Blue Mountains also present unique histories when compared with those of this study. At Mountain Lagoon (Robbie and Martin, 2007), the proportion of Casuarinaceae pollen is substantial at the beginning of the Holocene, then declines throughout the Holocene. *Allocasuarina torulosa* is more common at Mountain Lagoon than at any of the sites of this study. Pollen of swamp plants increase through the Holocene at Mountain Lagoon as the site developed from a lake in the early Holocene to a peat swamp in the mid-late Holocene. The Myrtaceae species identified are mainly different to the species of this study and the proportion of pollen remains much the same throughout the Holocene and only declines after European settlement. The species identified at Mountain Lagoon are often prized for timber (Robbie and Martin, 2007). The physical environment of Mountain Lagoon is totally different to that of the Blue Mountain sites: it is a small basin on Wainamatta Shale, in a particularly sheltered location.

Kings Waterhole, part of the Mellong Swamps in the Wollemi National Park, at 280 m altitude, has a 6 ka history (Black and Mooney, 2007). Myrtaceae (excluding *Melaleuca* spp.) and Casuarinaceae are prominent until about 4-3 ka, when Casuarinaceae begins to deline. At the same time, Restionaceae increases. After 3 ka, there is minimal Casuarinaceae and Restionaceae declines, but *Melaleuca* and Poaceae increase. After 1 ka, Myrtaceae decreases somwhat and Poaceae is prominent (Black and Mooney, 2007). This decline of Casuarinaceae after 3 ka is not seen in any of the sites of this study.

At Gooches Crater Swamp on the Newnes Plateau, between 900 and 1,200 m altitude (Black and Mooney, 2006), there is a 14 ka history of the vegetation. There is a moderate level of variability in the pollen assemblages, and the swamp vegetation varied from a wet heath with semi-permanent to permanent water to a fern swamp. The Myrtaceae and Casuarinaceae content is appreciable and continuously variable. The Asteraceae content is considerable (Black and Mooney, 2006), unlike the sites of this study, although the Newnes site has the greatest Asteraceae content of all the sites of this study.

Penrith Lakes on the Cumberland Plain just east of the Lapstone Monocline has 6 ka of Holocene history. The tree cover was very open in the mid Holocene, becoming somewhat more wooded in the late Holocene (Chalson and Martin, 2008), mirroring the findings of this study.

The rugged terrain of the Blue Mountains would have provided some isolation to each site so that each has its own sedimentary and vegetation history. Any climatic change or other regional event should imprint in these deposits, especially in the more environmentally sensitive sites.

Climatic change

The decline of the trees from the early Holocene to the mid Holocene in the sites at the higher altitudes, *viz.* Newnes, Katoomba and Kings Tableland, suggests that the climate had become drier. A detailed analysis of the climatic requirements of the *Eucalyptus* species also suggests a wetter early Holocene (Chalson, 1991).

Climatic trends in the mid Holocene are uncertain, for while the sites at higher altitudes were not wooded, sites at lower altitudes, i.e. Notts and Ingar Swamps, were wooded at this time. Trees returned to Katoomba about 3k yr, suggesting that the climate had become wetter. As discussed previously, the Katoomba catchment is narrower and steeper-sided, hence the most sheltered of the three higher altitude sites. Newnes and Kings Tableland, however, remained open with few trees, suggesting that if there was an improvement in the rainfall, it had not returned to the early Holocene levels. These uncertain trends continued into the late Holocene. About 2 kyr, there was an increase in the wooded vegetation, with more *Eucalyptus* at Warrimoo, more Casuainaceae at Kings Tableland and more *Melaleuca* at Newnes. The other sites, however, remained much the same. There probably was an increase in rainfall, but it was slight. The detailed analysis by Chalson (1991) came to similar conclusions: climatic changes in the mid and late Holocene are equivocal.

The climatic changes deduced from the this study are in general agreement with other sites in the Blue Mountains. The early Holocene is regarded as a climatic optimum when it was warmer and wetter (Allen and Lindesay, 1998). Evidence for the mid and late Holocene is variable, some indicating wetter, some drier conditions. Evidence suggests that the El Niño-Southern Oscillation (ENSO) phenomenon came into operation about 5 ka, with increasing seasonality. Thus from the mid Holocene, the climate became more like that of today, with more variability (Allen and Lindesay, 1998; Moy et al., 2002; Donders et al., 2007).

Fire history

Charcoal has been found in all of the sites and throughout all of the profiles. In the early Holocene, the charcoal content was low to moderate in Kings Tableland, Katoomba and Newnes. By mid Holocene, the quantity of the charcoal had declined in Katoomba and Newnes: there had been a change in the vegetation from more wooded in the early Holocene to less wooded in the mid Holocene, hence there may have been less fuel to burn.

In the mid Holocene at Notts, Ingar and Warrimoo Swamps, there is very little charcoal. All of the sites would have been wooded to some degree but not as much as in the late Holocene. The charcoal content increases at each site as the tree cover increased. In the late Holocene, charcoal content is variable, but mainly greater than in the mid Holocene. In the European zone, charcoal content is consistently high and the highest for the profile, with the exception of Katoomba. It may be that because of urban use of the swamp at Katoomba, fire was excluded. Within these trends, there may be the occasional single high value, but they do not form any pattern.

The interpretation of a charcoal record is problematical because so many factors are involved, e.g. fire frequency, intensity and transport of charcoal. The results of this study suggest that the greater the biomass, the more fuel there is to burn hence the more charcoal in the sediments.

The higher charcoal content of the European period suggests that fire regimes were changed with settlement. If Aboriginal people regularly burnt off the undergrowth and suppressed the shrubs, then the fuel load would be kept down. With European settlement and the cessation of traditional fire practices, it is possible that the woody shrubs became more common (Kohen, 1995; Ward et al., 2001). Under these conditions, the fuel load would increase. Today, species of *Baeckia, Kunzea* and *Leptospemum* are dominant on all of the swamps (Chalson and Martin, this volume). There is a trend for *Leptospermum* and *Kunzea* species to increase slightly in the late Holocene, with a further increase in the European Zone. These woody species would have had the capacity to produce more charcoal when burnt and be incorporated in the sediments, especially when growing on the swamp, when compared with the smaller sedges and reeds.

At Mountain Lagoon (Robbie and Martin, 2007), fire activity was low through the Holocene, until about 3-2 ka, when it increased. This pattern is similar to those of this study.

At Gooches Crater the charcoal content and hence fire activity fluctuates between 14 ka and 9 ka, then follows a period of low fire activity until about 6 ka, then a period of dramatic increase in fire activity in the late Holocene (Black and Mooney, 2006). Fire activity reaches unprecedented levels in the post-European period (Black and Mooney, 2006). The increase in fire activity in the mid Holocene is attributed to climate, in particular to the greater seasonality associated with the onset of the El Niño-Southern Oscillation (ENSO) phenomenon (Black et al., 2007). This pattern of fire activity is similar to that seen in the sites of this study.

At Kings Waterhole Swamp (Black and Mooney, 2007), the fire activity was low about 6 ka, then increased between 5-3 ka, after which it decreased to low levels to the present. This pattern of fire activity is quite unlike that of this study. It is thought that the decline in fire activity after 3 ka represented an alteration to Aboriginal management strategies associated with increasing population and/or the increased risk of conflagration in an ENSO-dominated climate (Black and Mooney, 2007).

Black et al. (2007) examined the charcoal record together with the archaeological record in an attempt to assess the likely effect of Aboriginal burning on the ecosystem. At Gooches Crater Swamp, the charcoal content appeared to be most influenced by climate, with an abrupt increase in the mid Holocene, perhaps associated with the onset of the modern ENSO-dominated conditions. Kings Waterhole also showed the abrupt increase in the mid Holocene, but there was a marked decrease in charcoal from about 3 ka. Lake Baraba also showed similar low levels of charcoal in the late Holocene. The archaeological records of all three regions showed increased activity/habitation in the late Holocene. It is thus possible that Aborigines strongly influenced fire activity in some places in the Sydney Basin during the late Holocene to prevent the risk of large intense fires as the ENSO-dominated climate became more prevalent (Black et al., 2007)

CONCLUSIONS

Seven swamps were studied and each had its own distinctive history. Where the *Eucalyptus* species were identified, the dominant species were different at each site, as they are today.

Similarities in the histories could be seen between some of the sites and are as follows:

In the early Holocene, the vegetation was more wooded, i.e. woodland or forest, which suggests a warmer wetter climate. Only the three sites at the highest altitudes had sediments of early Holocene age.

In the mid Holocene, the vegetation was less wooded in the three highest sites when the vegetation was probably shrublands and heaths, and this suggests a drier climate. Other sites at lower elevations were wooded in the mid Holocene.

The *Eucalyptus* species return to the less wooded sites towards the late Holocene. There is also a tendency for an increase in *Baeckea, Kunzea,* *Leptospermum* and *Melaleuca*, the woody shrubs. These woody shrubs are dominant on the swamps today.

There is some decline in Casuarinaceae in the European period but the *Eucalyptus* species are maintained at about the same level as in the late Holocene. The woody swamp shrubs increase in the late Holocene and European period.

The charcoal levels suggest that there was moderate fire activity in the early Holocene when the vegetation was more wooded, decreased fire in the mid Holocene when the vegetation was more open, with increased fire in the late Holocene and a further increase in the European period.

It is thought that the altered fire regime under European settlement encouraged the increase in woody shrubs on the swamps (and elsewhere) which in turn produced more charcoal.

These swamps on sandstone are highly erodable and a sand body at about 1.2-1.6 ka in the three most northerly and easterly swamps suggests they may have suffered an erosive event about that time. The destabilising event(s) which triggered this erosion is uncertain.

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APPENDIX A

Pollen type name on the pollen diagrams and the probable source in the vegetation.

Name of pollen type. Major pollen groups (A diagram)	Probable source in the vegetation and ecological inference. From PlantNet (2007)
Podocarpus	Probably *Podocarpus spinulosus*: sclerophyllous shrub/small tree
Pinus	*Pinus* sp(p). Introduced: Pollen input from urban/forestry areas.
Angophora/Corymbia	Species within the two genera: sclerophyll woodland
Eucalyptus/Melaleuca	Species within the two genera sclerophyll woodland/forest
Melaleuca styphelioides	*Melaleuca styphelioides*: moist stream bank habitat
Leptospermum/Baeckea	Species within the two genera: ?mainly swamp communities
Tristaniopsis	*Tristaniopsis* spp : moist habitats in sclerophyll communities
Unidetified Myrtaceae	All pollen types not identifiable further
Casuarinaceae	*Casuarina, Allocasuarina* sp(p): *A. distyla* and *A. nana* in this study
Poaceae	Native and exotic species in the family: open situations, dryland and swamp species
Restionaceae	All species in the family: swamp and dry land species
Cyperaceae	All species in the family: swamp and dry land species
Selaginella	All species in the genus: damp sites, edge of swamp
Gleichenia	*Gleichenia* sp(p): damp sites, edge of swamp
Other fern spores	Other ferns: many possible species
Names of shrubs and herbs (B diagrams)	
Grevillea acanthifolia	Shrub: swampy areas, sand or peat
G. sphacelata	Shrub: heath, dry sclerophyll forest
Grevillea	*Grevillea* sp(p): sclerophyllous understorey
Hakea	*Hakea* sp(p): sclerophyllous understorey
Persoonia pinifolia	Shrub: heath, dry sclerophyll forest
Persoonia	*Persoonia* sp(p): sclerophyllous understorey
Symphionema montanum	Shrub: heath or dry sclerophyll forest, wet or dry situations
Banksia	*Banksia* sp(p): sclerophyllous understorey
Other Proteaceae	Other taxa in the family: sclerophyllous understorey
Acacia	All species in the genus
Styphelia	*Styphelia* sp(p): sclerophyllous understorey
Monotoca	*Monotoca* sp(p): sclerophyllous understorey
Other Ericaceae	Other taxa in the family: sclerophyllous understorey
Rutaceae type	All taxa in the family sclerophyllous understorey
Pimelea	*Pimelea* sp(p): sclerophyllous understorey
Plantago	*Plantago* sp(p): native and introduced herbs
Haloragis	*Haloragis/Gonocarpus* sp(p): Damp sites, sclerophyllous understorey
Other tricolporate grains	Probably shrubs and herbs
Podocarpus	Probably *Podocarpus spinulosus*: sclerophyllous shrub/small tree
Micrantheum	Shrub: heath and dry sclerophyll forest, sandy infertile soils
Myriophyllum	Mainly aquatic herbs, also on damp ground around water bodies
Asteraceae/Liguliflorae	Fenestrate-grained taxa in the subfamily Liguliflorae: herbs
Asteraceae/Tubuliflorae	Echinate-grained taxa in the subfam. Tubuliflorae: shrubs and herbs
Chenopodiaceae	Ruderals, salt tolerant

APPENDIX B

Myrtaceae Pollen type name on the pollen diagrams and the probable source in the vegetation.

Name on the pollen diagrams	Probable source in the vegetation and ecological inference. From PlantNet (2007)
Angophora costata	Deep sandy soils on sandstone
Angophora floribunda	Usually on deep alluvial soils
A. costata x floribunda	-
Angophora	-
Baeckea/Leptospermum	Some species in swamp/moist habitats, also dryland species
Callistemon	Dry sclerophyll communities, some swamp species
Eucalyptus deanei	Tall wet forest, sheltered valleys, deep sandy alluvial soils
E. eugenioides	Dry sclerophyll or grassy forest, on deep soils
E. fibrosa	Wet or dry sclerophyll forest, on shallower, somewhat infertile soils
E. oblonga	Dry sclerophyll woodland, on extremely infertile, sandy soils
E. oreades	Wet or dry scleropnhyll forest, on poor skeletal or sandy soils
E. pauciflora/E. rubida	Grassy or dry sclerophyll woodland, on cold flats.
E. piperita	Dry sclerophyll forest/woodland, moderately fertile, often alluvial sandy soils
E. racemosa	Dry sclerophyll woodland, on shallow infertile soils
Eucalyptus type B	)
Eucalyptus type C	)
Eucalyptus type D	) For definition of Eucalyptus pollen types, see Chalson (1991)
Eucalyptus type K	)
Eucalyptus type M	)
Eucalyptus/Melaleuca	Species within the two genera: sclerophyll woodland/forest
Kunzea	Understorey sclerophyll forest, moist depressions
Leptospermum juniperinum	Swamp, heath and sedgeland, on sandy peat soils
L. polygalifolium	Dryland habitats and moist depressions
Melaleuca ericifolia	Heath and dry sclerophyll forest, streambanks and coastal swamps
M. styphelioides	Moist situations, often stream bank habitats
Melaleuca type B	)
Melaleuca type C	) For definition of pollen type, see Chalson (1991)
Melaleuca	For definition of *Melaleuca* pollen types, see Chalson (1991)
Myrtaceae type C	)
Myrtaceae type D	) For definition of pollen types, see Chalson (1991)
Unidentified Myrtaceae	All myrtaceous pollen types not identifiable further